Arthur Hollick

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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA.

Regular Publications.

The Society issues a single serial publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, lists of Fellows, etc., and the latter embracing the larger papers accepted for publication. The matter is issued as soon as possible after acceptance, in covered brochures, which are at once distributed to Fellows and exchanges. The brochures are arranged for binding in annual volumes, which are elaborately indexed.

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Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public
Proceedings of the Fourth Summer Meeting, held at Rochester, August 15 and 16, 1892. H. L. Fairchild, *Secretary*	1–12	.....	.....	\$0.10	\$0.20
Finite homogeneous Strain, Flow and Rupture of Rocks. G. F. Becker	13–90	.....	1–22	.70	1.40
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Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
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Irregular Publications.

In the interests of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the Proceedings also are authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 4 have been issued:

Editions uniform with the Brochures of the Bulletin.

Pages	13- 90,		430 copies.	January	3,	1893.
"	91-118,		180 "	February	21,	"
"	119-132, plate	1;	130 "	"	23,	"
"	133-146,		30 "	"	25,	"
"	147-166, plate	2;	55 "	"	25,	"
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"	191-204,		30 "	March	24,	"
"	205-224, plate	4;	180 "	April	14,	"
"	225-244,		130 "	May	20,	"
"	245-256,		80 "	June	8,	"
"	257-298, plates	5-9;	130 "	"	19,	"
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*Special Editions.**

Pages	379-393,†	30 copies.	September	23,	1893.	Without covers.
"	393-406, frontispiece;	30 "	"	23,	"	" "
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* Bearing the imprint [" From Bull. Geol. Soc. Am., Vol. 4, 1892."]
† Fractional pages are sometimes included.

CORRECTIONS AND INSERTIONS.

All contributors to volume 4 have been invited to send in corrections and insertions to be made in their contributions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 20, in formula for *tan* λ; *for* "a —" *read* a +.
" 21, first line of foot-note; " "unchanged length" " unchanged direction.
" 21, foot-note, 2d equation; " "y / x —" " y / x =.
" 27, third formula; " "a =" " — a =.
" 29, formulas (8); " "$cos\ (\nu - \mu)$" " $\sigma\ cos\ (\nu - \mu)$.
" 36, figure 3, letter the triangle in the upper right-hand corner, a b
c
" 37, formula for T, reverse signs of G and Q.
" 37, line 13 from top; *for* "page 34" *read* page 31.
" 59, last formula; " "4" " 2.
" 80, foot-note; " "p. 74" " p. 54.

The above are simply misprints, and the correct expressions were employed by Dr Becker in the deductions and computations.

" 185, erase the misplaced "s" to the left of figure 4.
" 223, line 20 from top; *for* "Wasacht" *read* Wasatch.
" 304, " 8 " " " "magnatic" " magnetic.
" 306, " 2 " bottom; " "no. 85" " no. 65.
" 314, " 14 " top; " "Walhnapital" " Walhnapitae.
" 318, lines 15 and 17 from top; " " "
" 331, line 5 from top; " "Walter McOuat" " Walter McQuat.
" 333–348; " "Contchiching" " Coutchiching.
" 340, line 13 from top; " "Vermiline" " Vermilion.
" 341, lines 14 & 20 from bottom; " "Rat Roat" " Rat Root.
" 342, line 1 from bottom; " "no. 9" " no. 1.
" 346–348; " "Atic Oban" " Atic Okan.
" 362, line 20 from top; *after* ("true meridian") *omit* and.
" 363, " 6 " " *omit* "obviously."
" 363, " 8 " " *after* "Carboniferous" *insert* systems.
" 363, " 9 " " *omit* "systems."
" 364, " 8 " bottom; *after* "courses" *omit* of them.
" 365, " 14 " top; *for* "*Belanus*" *read* *Balanus*.
" 366, " 4 " bottom; *enclose* "*Yoldia arctica* of Sars" *in parenthesis*.
" 369, " 6 " top; *for* "has been formed" *read* has also been formed.
" 409, " 22 " bottom; " "B. G. Harrington" " B. J. Harrington.
" 409, " 13 " " " "these" " them.
" 409, " 7 " " " "*Sasiothrix*" " *Lasiothrix*.
" 410, " 7 " top; " "hair" " base.
" 410, " 10 " " *after* "closely" *insert* or loosely.

Page 410, line 16 from top; *after "Palawsaccus" insert* *
" 410, " 16 " " *for "Palawsaccus" read Palæosaccus.*

Also at the bottom of the page insert the following foot-note, to which the star should refer:

* It has since been described and figured by Dr G. J. Hinde, under the name *Palæoaccus dawsoni*, in the *London Geological Magazine*, February, 1893, p. 56.

" 410, line 24 from top; *for "cusiformis" read ensiformis.*
" 410, " 23 " " " "*Astiopollition*" " *Astropolithon.*

Additions to Newberry Bibliography.

Page 400, between lines 12 and 13 from top;	*insert* Remarks on copper Ores in the Triassic Sandstones of the United States: *Proc. New York Lyc. Nat. Hist.*, vol. ii?, 1874, pp. 16, 17.
" 401, " " 13 and 14 " bottom;	" Remarks on the Genesis of the Newark Sandstones contiguous to the Palisades, New Jersey: *Proc. New York Lyc. Nat. Hist.*, vol. i, 1870–1871, pp. 131, 133, 134, 137.
" 402, " " 18 and 19 " "	" Remarks on Serpentine of Staten Island: *Trans. New York Acad. Sci.*, vol. i, 1881, pp. 420–422.
" 402, " " 7 and 8 " "	" Remarks on the intrusive Character of the Trap of Bergen Hill, New Jersey: *Trans. New York Acad. Sci.*, vol. ii, 1882–'83, p. 120.
" 403, " " 22 and 23 " top;	" Remarks on the former Extent of the Newark System: *Trans. New York Acad. Sci.*, vol. vii, 1887, p. 39.
" 404, " " 7 and 8 " "	" Description of new fossil Fishes from the Trias: *Ann. New York Acad. Sci.*, vol. i, 1879, pp. 127, 128.
" 404, " " 16 and 17 " bottom;	" On *Dendrophycus triassicus*: *American Naturalist*, vol. xxiv, 1890, pp. 1068, 1069.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 4, PP. 1-12 DECEMBER 27, 1892

PROCEEDINGS OF THE FOURTH SUMMER MEETING, HELD AT ROCHESTER, AUGUST 15 AND 16, 1892

H. L. FAIRCHILD, *Secretary*

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SESSION OF MONDAY, AUGUST 15

The Society met at 2.30 o'clock p m, in the geological lecture-room, Sibley Hall, University of Rochester; the President in the chair, and about twenty-five members present.

The President, Mr G. K. Gilbert, opened the meeting with appropriate introductory remarks.

ELECTION OF FELLOWS

The Secretary announced as the result of the balloting for the election of Fellows that the following persons were elected Fellows of the Society :

ALFRED E. BARLOW, B A, M A, Geological Survey, Ottawa, Ont. Field Geologist; now engaged in stratigraphical geology and working on the Archean rocks north of lake Huron.

HENRY PEARETH HAWDON BRUMELL, Geological Survey, Ottawa, Ont. Assistant, Division Mineral Statistics and Mines; now engaged in mining geology and geology of natural gas and oil.

Marius Robison Campbell, U. S. Geological Survey, Washington, D. C. Geologist; now engaged in stratigraphy and structure of the Paleozoic rocks of the Appalachian province.

Antonio del Castillo, School of Engineers, City of Mexico. Engineer of Mines and Director of National School of Engineers. Director of the Geological Commission for the preparation of the Geological Map of the Republic of Mexico.

Harold W. Fairbanks, B S, San Diego, Cal. Geologist on staff of State Mining Bureau; now engaged in general field geology.

Leon S. Griswold, A B (Harvard, 1889), 238 Boston St, Dorchester, Mass. Geologist; engaged in field work on Triassic area of Connecticut.

Albert P. Low, B of Sc, Ottawa, Ont. Field Geologist Geological Survey Department; now engaged in the study of the Archean.

Vernon Freeman Marsters, A B, Bloomington, Ind. Associate Professor of Geology in Indiana State University; now engaged in the study of general geology and petrography.

Albert C. Peale, M D, Washington, D. C. Geologist United States Geological Survey; engaged in structural geology and stratigraphy of northeastern Rocky Mountain region.

William B. Scott, M A, Ph D (Heidelberg), Princeton, N. J. Professor, College of New Jersey; now engaged in study of vertebrate paleontology.

Charles Henry Smyth, Junior, A B, Ph B, Ph D, Clinton, N. Y. Professor of Geology in Hamilton College; now engaged in the study of the geology of the western Adirondack region.

Joseph Stanley-Brown, Washington, D. C. Assistant Geologist United States Geological Survey; now engaged in the study of petrography and structural geology in northwestern United States.

Charles Livy Whittle, West Medford, Mass. Assistant Geologist United States Geological Survey; now engaged in field work in the Archean rocks of southern Vermont.

The President announced that the Council had determined that other sessions of this meeting should be held on Tuesday, August 16, at 10 o'clock a m and at 2 o'clock p m.

No further business being offered, the President declared the scientific work of the meeting in order, and announced the first paper on the printed program, which, in the absence of the author, was read by W J McGee:

NOTES ON THE PHOSPHATE FIELDS OF EASTERN MARION AND ALACHUA COUNTIES, FLORIDA

BY LAWRENCE C. JOHNSON

The paper was discussed by Charles H. Hitchcock, E. W. Claypole, R. A. F. Penrose, Junior, I. C. White and W J McGee.

The second paper presented was—

ON THE DENTITION OF TITANICHTHYS AND ITS ALLIES

BY E. W. CLAYPOLE

On behalf of the Committee on Photographs Mr C. W. Hayes announced that the photographs recently acquired were displayed in the adjoining hall of the University Geological Museum.

The following paper was then read:

STUDIES OF THE CONNECTICUT VALLEY GLACIER

BY C. H. HITCHCOCK

Reference may be made first to the literature of the subject by Professor E. Hitchcock, who believed the ice marks in general were produced by icebergs, and recognized true glacial phenomena in the Westfield and Deerfield river valleys tributary to the Connecticut. This was in 1853. Ten years later Professor J. D. Dana commented upon these and related facts, and presented the view that the markings were not produced by local glaciers, but were made by the general ice sheet, the variation in direction having been due to pressure. Professor Louis Agassiz, in 1872, recognized local glaciers entirely subsequent to and independent of the main ice sheet in a part of the White mountains. The present author has also recorded similar views in various papers and reports.

A more thorough examination of the main Connecticut valley in the vicinity of Hanover, New Hampshire, has recently been made in order to afford a better understanding of the facts. Over a territory thirty miles long and from ten to fifteen miles wide nearly every ledge has been scrutinized, and the directions of striæ recorded. The record includes two hundred observations within this area. The attempt was made to have this record exhaustive, and to include the markings on both sides of the valley movement. The general conclusion is that two movements are indicated: first, in the direction S. 30° E., principally on the highland borders; secondly, in the direction S. 10° W., existing only in the depressed area. More specific conclusions are the following:

1. In addition to the Connecticut valley movement in the direction indicated by the topography, there were numerous branches to it, corresponding to the smaller tributaries. The phenomena observed authorizing this generalization are striation and the transport of bowlders. The test cases are where the movement has been in direct opposition to the general southeasterly current. Thus, on adjacent ledges two miles north of Hanover, there are striæ pointing N. 60° W., and others S. 20° W., the first being tributary to the second, and less deeply scored. Next, there are a dozen excellent examples of the westerly transportation of large blocks of a peculiar protogene-gneiss. These occur in Lebanon, Hanover and Oxford, and in a few cases there are striæ to correspond, trending southwesterly. This particular rock occurs only on the eastern side of the valley, and it is not possible, therefore, to say that its fragments were transported by ice in the course S. 30° E.

2. Near the upper limit of the valley striations there are several examples of the S. 30° E. course, which are isolated and situated in the midst of the S. 10° W.

markings. So far as observed, the first occupy depressions in the ledge, or else are located on the lee side of the valley scorings. Our inference is that the S. 30° E. markings were once quite abundant and have been mostly obliterated by the later local glacier. These examples are not confined to the eastern border of the valley, but have been found elsewhere in the lower regions.

3. While it cannot be regarded as a universal fact, many observations show that flat bowlders imbedded near the surface of the till have been striated by the valley movement as well as by the older action. Hummocks of till can be referred to either of the movements by observing these directions. It would appear that the older till had been deposited before the local glacier had an existence. Agassiz has described this same condition of things in the Bethlehem glacier. The most obvious effect of the later movement has been the removal of the rough blocks from the surface of the older till, and hence smoothed hummocks indicate a later and local movement.

4. Bowlders have been carried by ths southeasterly movement entirely across the valley and lodged upon the farther side. As our studies have been mainly confined to the depressed region, many cases of this kind have not been observed. The best illustration of it is the presence of numerous bowlders of the mount Ascutney granite in Claremont and Newport, New Hampshire. This mountain lies in the midst of the S. 10° W. striation, but blocks have been carried from it toward the southeast, evidently before the glacier commenced to move down the valley. Others have been carried southerly, as if caught by the later current.

5. As a rule, the line is sharply defined between the two directions of striation.

6. The valley movement reached the altitude of 900 feet above the sea in Claremont, 1,600 to 1,800 feet in Hanover on the eastern border, 1,900 feet on the western border in Norwich, Vermont, and perhaps 2,500 feet on mount Ascutney. This mountain is a cone, somewhat west of the median line of the valley.

7. The noted esker described by Warren Upham between Windsor, Vermont, and Lyme, New Hampshire, occupies the area in question, and the stones found in it correspond to ledges on the west and north, but not to those on the eastern side of the valley. Pebbles of porphyry from the White mountains can always be found among them by a diligent search. These could not have been brought by the general ice movement of S. 30° E. The distance of transportation is often as much as sixty miles.

The evidence of the presence of a local glacier down the Ammonoosuc river, a principal tributary of the Connecticut, is more pronounced than anything that can be adduced for the area now being discussed. It must have been the upper part of the same local glacier.

The papers by the earlier authors were based upon the notion that a single ice sheet only is required to account for all the glacial phenomena, and that the Connecticut Valley glacier came into being in the decline of the ages after the ice had ceased to be supplied from Canada. The facts, so far as known in New England, do not necessitate the existence of more than one ice age, but it is conceivable that the system of glaciers radiating from the Green and White mountains may represent a second ice sheet. In this connection the attention of glacialists is called to the interesting southwesterly striation found upon certain highlands in southern Vermont and western Massachusetts, as described in Geology of Vermont, volume 1, page 79. These evidently represent a phase of glaciation different from the one described in this paper.

A free discussion followed the reading of this paper. Professor W. H. Niles, speaking of his observations in the Alps, said—

About the Matterhorn and the Weisshorn I have observed thin glaciers with a movement different in direction from the thicker glaciers which formerly existed in the same places. I believe that under some conditions the upper surface of a glacier might have a different direction of movement from the lower surface, and have seen glaciers moving over till, kames, etc. In one instance I had the fortune to observe under favorable conditions a glacier passing over a surface sparsely strewn with bowlders, and at one point found that a bowlder was being slowly pushed forward by the ice, but at the same time the body of the glacier moved much more rapidly than the bowlder, so that its bottom was marked by a long groove extending some yards down stream from the bowlder.

Professor I. C. White observed—

Contrary to my former belief, I now know of no mountains in northern Pennsylvania which were not buried in the Pleistocene ice sheet.

Mr McGee remarked—

The paper and the discussion suggest a feature of ice movement not always appreciated, which is well exemplified in northeastern Iowa about the margin of the driftless area. There were in this region two ice invasions of approximately but not exactly equal extent; in the first the ice advanced farther in the north and not so far in the south as in the later invasion, so that the drift bordering the driftless area represents the lower till or older sheet in the north, the upper till or later sheet in the south. Now both in the north, about the headwaters of Oneota river, and in the south, about the lower reaches and tributaries of the Maquoketa, there is a remarkable relation between the elements of the topography and also between the distribution of the drift and the surface configuration—a relation best displayed in southeastern Jackson county and northeastern Clinton county. Here the characteristic curves of the glacial topography pass gradually into the more strongly accented lines of the water-cut topography by which the driftless area is distinguished, and it is significant that the transition from ice-molding to water-carving is not only horizontrl but vertical—that first the bottoms, later the mid-sides, and finally the rims of the valleys lose the glaciated curves and assume the water-cut angles; and this is especially true of the transverse valleys. Moreover, in some cases the transverse valleys are partly lined with an ice laid deposit differing from the prevailing drift of the region in that it is made up almost wholly of local débris, sometimes apparently removed but a few feet or rods from the parent ledges; while even the furthermost traces of the drift are made up predominantly of far-traveled crystalline rocks, and occupy faintly glaciated summits some miles beyond the limit of ice-molding in the valleys. In brief, both the distribution of the drift and the topographic configuration indicate that the thin margin of the ice bordering the driftless area first pushed into and filled certain transverse valleys, and then rode over the imprisoned ice as on a bridge, the surface of slip being transferred from the bottom of the valley to the plane of its rim. In valleys oblique

to the ice-flow the slip appears to have been divided between the valley-bottom and the plane connecting its walls.

Mr Warren Upham said—

Instead of attributing the courses of glaciation in the Connecticut valley to a local glacier, as suggested by Professor Hitchcock, my observations of the glacial drift in that valley and over the adjoining country lead me to think that the striæ bearing toward the south and west of south are due to local deflection of currents of the ice sheet during the time of its departure, rather than either to any glacier later existing there or to longer continuance of a remnant of the ice sheet there than on the higher land at each side. The Connecticut valley esker (called a kame in Geology of New Hampshire, volume iii) was traced by Professor Hitchcock and myself along the axis of this part of the Connecticut valley for a distance of about twenty-five miles, from Lyme, New Hampshire, to Windsor, Vermont. It is believed to have been deposited in the ice-walled channel of a superglacial stream near its debouchure from the ice sheet to the land from which the ice had retreated. The size and extent of this esker and its material, which is obliquely bedded gravel and sand without bowlders, show that it was formed by a large superglacial river draining a considerable area of the melting ice sheet. When the ice had become thinned by ablation, its surface here descended from each side toward the glacial river by which the esker was being formed, and there was probably also some indentation or embayment of the receding glacial boundary at the river's mouth in the valley. At this time the currents of the ice sheet which had passed southeastward even in the bottom of the valley, as known by the oldest sets of striæ there noted by Professor Hitchcock, became deflected, as I think, toward the south and west of south, taking the course of the valley, in obedience to the law that the currents of the outer part of the ice must everywhere turn perpendicularly toward its edge.

Professor Niles added—

The Alpine glaciers suggest a relation between ice and topography quite different from that assumed by Mr Upham. During past ages glaciation was much more extensive in the Alps than at present; yet as the ice retreated, it did not withdraw from the valleys but disappeared from the divides and shrank into the valleys; and to-day, as probably at every stage since the Alpine ice reached its greatest extension, the margin of the ice is not indented by notches coinciding with the valleys, but is marked by streams of flowing ice pushing far below the general snow level.

Mr McGee added—

While analogies drawn from Alpine glaciers are of great use in researches concerning ancient glaciers of this country, it should be borne in mind that ice-work is not necessarily similar in regions of high relief like the Alps, and in regions of low relief like the plains of the Mississippi valley and perhaps also the plateaus of New England. In regions of high relief the terrestrial surface is rugose and the general flow of the ice is obstructed by the inequalities. Accordingly, while the

glacier may, if of continental type and of sufficient thickness, assume a fairly uniform general slope and a moderately definite direction of general movement, the prevailing movement, particularly in the lower portions of the sheet, may be purely local and determined by the local slopes. This predominance of local over general movement is magnificently illustrated along the lower reaches of Frazer river in British Columbia, where the lesser mountains, up to three or four thousand feet in altitude, are converted into huge tors; but while the prevailing trend of the great flutings in which the direction of flow is recorded is toward the coast, the trend is by no means uniform, and many flutings indicate prevailing movement down the slopes, such as might be expected in a slowly settling névé. Now in such regions as British Columbia and the Swiss Alps, this local downward impulse must so far preponderate as to keep the valleys filled, howsoever rapidly ablation may progress, leaving the divides to be first laid bare. On the other hand, there is good reason for believing that in the plains of the upper Mississippi valley the ice pushed forward under a general impulse which so far preponderated over the local impulse down the gentle slopes that when ablation commenced, superglacial streams were formed and gradually cut through the ice and into the subterrain, so that the entire surface became diversified by a drainage corresponding in many respects to that of to-day—in short, in northeastern Iowa at least, this superglacial drainage was superimposed upon the land surface and remains to-day a record of the surface configuration of the continental glacier. These types of glacial action must be carefully distinguished; but there is perhaps a question as to which type was represented by the ice-work of New England.

Professor Claypole drew illustrations from Alpine glaciers. He thought the Connecticut valley glacier more comparable to Alpine valley glaciers, and particularly to the lower part of the Mer de glace.

Mr Gilbert regarded the possibility of upper ice moving over inferior ice as demonstrated. He had observed phenomena which nothing else could explain. In the "finger lakes" of New York each valley has been shaped by undercurrents in the ice, while the region has been planed differently.

Professor Hitchcock regarded the Connecticut valley glacier as a local glacier from the White mountains toward the close of the glacial episode.

Professor John C. Branner read the next paper:

THE OZARKS AND THE GEOLOGICAL HISTORY OF THE MISSOURI PALEOZOIC

BY G. C. BROADHEAD

Remarks were made by J. J. Stevenson and H. S. Williams.

The Society then adjourned until the following day.

Session of Tuesday Morning, August 16

The Society assembled at 10.15 o'clock a m, President Gilbert in the chair.

The first paper read was—

PHASES IN THE METAMORPHISM OF THE SCHISTS OF SOUTHERN BERKSHIRE

BY WILLIAM H. HOBBS

This paper is published elsewhere in this volume.

The next paper was then presented by the author, and was illustrated with maps and drawings:

THE ONEONTA SANDSTONE AND ITS RELATIONS TO THE PORTAGE, CHEMUNG AND CATSKILL GROUPS

BY JAMES HALL

During a long discussion, Professor H. S. Williams spoke as follows:

It is difficult to map such formations, the physical conditions of deposition being related to the faunas in a very complicated manner. The physical conditions change the character of the deposits, while the fauna may persist; a series of dissimilar rocks being together one faunal formation. In determining the extent of formations paleontology outranks lithology.

In reply to a question by Professor J. J. Stevenson, Dr Hall said—

The Chemung wedge is lithologically distinct as well as in its fossils.

Professor Stevenson compared Dr Hall's section of strata with his own New York section and with Professor I. C. White's observations in Pennsylvania. Professor White stated that a similar formation extends from New York to White Sulphur springs, in Virginia, and even into Kentucky. He would call it all Chemung. Professor E. W. Claypole spoke in compliment of the paper, which contained observations made before many Fellows of the Society were born. He said that in Ohio shales replace the sandstones of New York and Pennsylvania. During Devonian time physical conditions greatly changed in a few hundred miles from east to west; in western Pennsylvania changes occurred within an extent of only twenty-five miles. The President spoke of the classification of formations and the principles of nomenclature, and remarked that nature is more transitionary than our nomenclature can adequately present.

In closing the discussion Dr Hall spoke of the long persistence of faunas, through important changes of receding and reädvancing sea-

shores, local deepening of the ocean, etc. For colors on maps he preferred designating the lithology.

This paper is printed in full elsewhere in this volume.

The concluding paper of the morning session was read in the absence of the author by Mr R. S. Woodward:

FINITE HOMOGENEOUS STRAIN, FLOW AND RUPTURE OF ROCKS

BY G. F. BECKER

This paper is printed in full in the succeeding pages of this volume.

Session of Tuesday Afternoon, August 16

The Society was called to order by President Gilbert at 2.10 o'clock.

A paper was read by the author under the following title:

CONDITIONS OF ACCUMULATION OF DRUMLINS

BY WARREN UPHAM

A short abstract of this paper is given in The American Geologist for October, 1892, volume xii, page 218, and it is published in full, with additions, in the same journal for December, 1892.

Professor R. D. Salisbury remarked—

It seems to me that the use of the term "englacial drift" is objectionable. I regard the foliation of drumlins as due to great pressure. The arrangement of drumlins is not parallel to the terminal moraine; they are sometimes at right angles to it. Drumlins seem to me to be a normal feature of the drift and ought to be common; their absence is more singular than their occurrence. Some are found at right angles to the direction of ice movement, but they were always formed near the ice margin, and were englacial and subglacial.

Mr F. J. H. Merrill remarked—

I have found Cretaceous rocks in the Long island drift hills, which seem to me to have a bearing on the question and to indicate the subglacial origin of the drift.

Mr W J McGee said—

I agree with Professor Salisbury in regarding drumlins as normal phenomena. Their formation is illustrated in homely fashion by the frequent accumulation of masses of débris beneath any heavy body dragged on the ground; they well ex-

emplify the physical law that "starting friction" is greater than "moving friction." They should be looked for, not in the area of active glacial degradation, but about the critical line at which deposition began, *i e*, the point of oscillation between degradation and deposition.

Mr Upham remarked—

I must continue to regard the isolation and strange distribution of drumlins as a very singular, important and unexplained feature.

The next paper was—

THE EXTRA-MORAINIC DRIFT OF THE SUSQUEHANNA VALLEY

BY G. FREDERICK WRIGHT

Professor R. D. Salisbury and Mr W J McGee remarked upon the matter of the paper, challenging the observations and inferences of the author.

The next paper was as follows:

A NEW TÆNIOPTERID FERN AND ITS ALLIES

BY DAVID WHITE

Remarks were made by Professor E. W. Claypole and by the author. The paper in full is printed in later pages of this volume.

The two following papers were read consecutively by the author:

THE OVERTURN OF THE LOWER SILURIAN STRATA IN RENSSELAER COUNTY, N. Y

BY A. S. TIFFANY

ANCIENT WATERWAYS.

BY A. S. TIFFANY

[*Abstract*]

The writer gave a brief account of an ancient waterfall in a paper read before the American Association for the Advancement of Science at Ann Arbor, and published in pamphlet form in 1885. This waterfall eroded the hard, horizontally disposed Corniferous limestone of what is now Rock island (Illinois) to a depth of 70 feet and a width of 900 feet. The cavity was afterward filled with Coal Measure shales. The boring of artesian wells in Illinois and Iowa has since developed a number of excavations of still greater depth filled with drift.

At Dixon, Illinois, at an altitude of 718 feet above sea-level, a well drilled by Mr Wilson ran through 150 feet of bowlder clay, though the Galena and Trenton limestones of the vicinity rise in cliffs many feet above the top of the well (see Geol. Ill., volume v, pages 128–130).

At Victor, Iowa county, Iowa (elevation, 806 feet), an artesian boring went through 348 feet of drift, while at Homestead, 22 miles eastward (elevation, 866 feet), the Kinderhook has but a light covering of drift. Again, at Wilton, Muscatine county, Iowa (elevation, 672 feet), about 50 miles east of Homestead, an artesian well went through drift, including a large bowlder, to a depth of 300 feet; while at Limekiln, six miles northwestward, the Niagara limestone is in place at a higher elevation, and at Moscow, only four miles west of Wilton (elevation, 652 feet), the Hamilton shales form the river bluffs.

Phenomena analogous to those of Rock island occur in Missouri, as shown by the Report on Coal, published by Winslow in 1891. This preliminary report gives a map of the coal mines and coal pockets in rocks of different ages in twenty counties. They are horizontally disposed basin-shaped cavities, with diameters of 800 to 1,000 feet, from 20 to 80 feet deep, filled with strata of coal and shale, bituminous and cannel coal frequently occurring in the same pocket. These pockets range from the margin of the Coal Measures in place to 120 miles distant from them. Swallow located 23 of these pockets in Cooper county, four of them lying within five miles above Booneville. Since Swallow's report was published, many more of these pockets have been explored and the coal worked out. They extend to near Booneville, and lie in close proximity to the beds from which Messrs Blair and Sampson and the writer made large collections of Keokuk crinoids, the Keokuk rocks rising in the sloping cliff more than 50 feet above the coal. The coal beds vary in thickness from 20 to 36 feet, while the accompanying shales are very thin. According to Swallow, these abnormal deposits are found in ravines and cavities of denudation in rocks of all ages, from the *Archimedes* limestone down to the Calciferous. The well-known bed in Calloway county is said to be over 80 feet thick.

These excavations in rocks of different ages show the enormous erosion which took place in the Mississippi valley anterior to the coal period, and the basin shape of some of them suggests that they were produced by ancient waterfalls.

Remarks were made by E. W. Claypole and Samuel Calvin.

The three following papers were read by title:

SOME DYNAMIC AND METASOMATIC PHENOMENA IN A METAMORPHIC CONGLOMERATE IN THE GREEN MOUNTAINS

BY CHARLES L. WHITTLE

PRELIMINARY NOTES ON THE GLACIATED AREA OF NORTHEASTERN KANSAS

BY ROBERT HAY

THE THICKNESS OF THE DEVONIAN AND SILURIAN ROCKS OF CENTRAL NEW YORK

BY CHARLES S. PROSSER

The President made a few appropriate remarks and declared the meeting adjourned.

Register of the Rochester Meeting, 1892

The following Fellows were in attendance at the meeting:

Henry M. Ami.
John C. Branner.
Samuel Calvin.
Edward W. Claypole.
Aaron H. Cole.
Herman L. Fairchild.
P. Max Foshay.
Homer T. Fuller.
G. K. Gilbert.
James Hall.
C. Willard Hayes.
Robert T. Hill.
Charles H. Hitchcock.
William H. Hobbs.
H. C. Hovey.
Joseph P. Iddings.
Joseph Le Conte.
Thomas H. McBride.
W J McGee.
F. J. H. Merrill.
William H. Niles.
R. A. F. Penrose, Junior.
R. D. Salisbury.
John J. Stevenson.
A. S. Tiffany.
Warren Upham.
David White.
I. C. White.
R. P. Whitfield.
H. S. Williams.
Robert S. Woodward.
G. Frederick Wright.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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FINITE HOMOGENEOUS STRAIN, FLOW AND RUPTURE OF ROCKS.

BY GEORGE F. BECKER.

(*Presented before the Society August 16, 1892.*)

CONTENTS.

Phenomena and Plan of Discussion.

Evidences of Movement.—All observers are aware that few rock masses are continuous for any considerable distance. It is seldom that more than a few yards of a rock exposure can be examined without revealing joints, fissures or slickensides. Still more frequently rock masses show slaty or schistose cleavage,* impressed upon them by dynamical causes. In a very great proportion of such cases a little attention also discloses

*Schist and the adjectives derived from it are used in literature in somewhat variable senses. As I use it, schist denotes cleavable rocks which are allied to slates, but in which the cleavage surfaces are not all sensibly parallel to one another as they are in true slate. By no means are schists all crystalline or metamorphic.

the fact that the partings are locally arranged on a definite system. In slaty cleavage the cleavage planes are substantially parallel and very close together; in flags of the slaty class the intervals between cleavage planes are greater; in schists the partings range through small angles, and in these last rocks there are frequently two sets of partings, each cleavage making a small angle with others of the same set, but a large angle with those of the other set. Where the rock is divided by cracks these are often parallel and spaced with a considerable approach to uniformity. Sometimes they occur at a fraction of an inch from one another, while in other instances they are rods apart. In still other cases there are two systems of such cracks crossing one another at right angles, or at angles which approach to right angles. Not infrequently such a double system of fissures is accompanied by a second of like character, at right angles to it, dividing the rock into polyhedral fragments of greater or less size.

Slaty cleavage is at present regarded by most geologists as due to a pressure acting in a direction perpendicular to the planes of cleavage, and this opinion is supposed to be well supported by experiments. Indications are not wanting, however, that many observers are ill satisfied with this explanation. Less attention has been paid to jointing, concerning which there is no consensus of opinion. By some it is considered as due to tensile stresses, while others insist on its intimate association with cleavage. Jointing is also often treated as distinct from faulting and as being unaccompanied by any relative movement of the joint walls. No systematic attempt appears to have been made to elucidate these various structures, which are generally recognized, however, as at least sharing a dynamic origin. Even the experiments on cleavage seem to me not to have been studied with as much care as they deserve.

Scope of the Inquiry.—Orogeny can never be satisfactorily discussed until the dynamic significance of cleavages and cracks is clear. A necessary step toward this end consists in the elucidation of those areas, great or small, throughout which the phenomena are uniform; for, however complex the conditions may be in any body of rock, they may be considered as uniform over a sufficiently small fraction of the whole mass.

Even this seemingly modest step cannot be completed in the present state of science. In the mechanics of artificial structures and machinery it is sufficient to discuss very small deformations, for such only are admissible. In geology this is wholly insufficient, the strains frequently being of enormous amount; so great indeed that laboratory experiments hardly aid one to conceive that they are possible. Yet there is no doubt among geologists that pebbles, even of quartzite, in conglomerates are not infrequently elongated by pressure to double their original length without rupture. Thus in geological mechanics it is absolutely essential

to consider finite strains as well as infinitesimal ones.* Now, to discuss such strains completely it would be needful to know the relation between finite strains and the forces which produce them. This relation is not yet known.

One might infer that until it were ascertained discussion would be useless. I hope to show, however, that many relations of finite strain can be elucidated without the assumption of any law connecting stress and strain, and that these relations are of great assistance in the study of orogeny.

The general principles governing finite distortion have, of course, been indicated by natural philosophers; but little attention has been given to their development, because the theory of finite strain is needless for computation of machinery, while this subject will not offer much purely mathematical interest until the stress-strain law is known experimentally. In particular, but little attention has been paid (so far as I am aware) to the planes of maximum strain, which turn out to be those in which geologists have a special interest.†

In the following pages the attempt will be made to develop all the manifestations of uniform or homogeneous finite strain in rock masses regarded as isotropic, exhibiting viscosity and capable of flow, which can be elucidated without assuming a law connecting stress and strain. For this purpose finite strain must first be discussed by itself; then it must be considered just how far the relations of stresses are capable of coördination with those of strain. The influence of viscosity and solid flow must next be shown. Readers willing to assume that these subjects have been logically treated will probably skip them and proceed to the geological applications which follow. Finally, the results will be compared with actually observed phenomena and with the experiments which several investigators have made on slaty structure.

Finite rotational Strain.

LIMITATIONS OF THE PROBLEM.

The mechanical effects short of rupture which force can produce in any mass are translation, rotation, dilation and deformation. The effects of mere translation may be considered separately from the other effects of force, or, in other words, one may consider these other effects relatively to some chosen point of the body itself.

* I have previously endeavored to show that some fissure systems are satisfactorily explained on the hypothesis of small strains: Bull. Geol. Soc. Am., vol. 2, 1891, p. 49.

† On finite strain consult Thomson and Tait, Nat. Phil., 1879, sec. 181; and Ibbetson, Math. Theory of Elasticity, 1887, p. 69. I am much indebted to both authorities.

If any one point of a body is fixed in space, the mass can be brought from its original orientation into any other orientation by simple rotation about some one axis passing through the fixed point. This is a well known and very fundamental theorem, one of the many which bears Euler's name.

In homogeneous strain each elementary cube of the mass is deformed in the same manner as any other; each straight line in the unstrained mass therefore remains a straight line after strain, being elongated or deflected to the same extent as any of the lines parallel to it, and all lines originally parallel remain parallel. Hence any sphere in the unstrained mass becomes an ellipsoid, and all such ellipsoids are similar.

Irrotational strain is a term applied to a change in form and dimensions unaccompanied by any change in the direction of the axes of the strain ellipsoid. It is manifest that any dilation and any desired ratio between the axes of the strain ellipsoid can be produced without changing the direction of these axes.

Hence if the changes in a homogeneously strained elastic mass are regarded relatively to any one point of it, any change in the relations of its parts may be considered as compounded of a rotation about a single axis into the required orientation and an irrotational strain.

There is no necessary connection between the axes of strain and the axis of rotation, and the latter will not in general coincide with any of the strain axes. The rotation in the general case is resoluble into three partial rotations about the three strain axes.

For the purposes of this paper, it is both necessary and sufficient to examine the conditions affecting the mass in the principal sections of the strain ellipsoid. This is equivalent to selecting any one such section and considering the movements relatively to it. When such a selection is made, the rotations of the plane itself on axes drawn in it are eliminated, and only the rotation of the mass about a line perpendicular to the plane of reference retains its significance.

The first subject of discussion therefore is an ideally elastic mass with one point fixed when subjected to any distortions, however great, which will produce rotation about not more than one axis of the strain ellipsoid.

DISPLACEMENTS.

General Conditions.—Let the center of inertia of a mass remain at rest; let any other point or points of it be moved in planes parallel to the $x\,y$ plane without limitation, provided only that the strain shall be homogeneous, but let every plane originally parallel to that of $x\,y$ remain parallel to it, so that deformation parallel to $o\,z$ shall consist simply of

changes of length. Then, if $x\ y$ are the original coördinates of any point and $x'\ y'$ its final coördinates these positions are connected by linear relations,

$$x' = (1+e)\,x + by\,;\ y' = ax + (1+f)\,y\,;\ z' = (1+g)\,z\,;$$

or,

$$x = \frac{(1+f)\,x' - by'}{(1+e)\,(1+f) - ab}\,;\ y = \frac{(1+e)\,y' - ax'}{(1+e)\,(1+f) - ab}\,;\ z = \frac{z'}{1+g}.$$

Here a, b, e, f, g are absolutely arbitrary and have the same value at all points of the mass.* They are the coördinates after strain of particular points. Denoting $x = 1, y = 1, z = 1$, by $(1, 1, 1)$, points originally at $(1, 0, 0)$, $(0, 1, 0)$, $(0, 0, 1)$, are transposed to $(1 + e, a, 0)$, $(b, 1 + f, 0)$, $(0, 0, 1 + g)$.

When the strain is so small that the squares of the displacements are negligible, a, b, e, f, g are to be treated mathematically as infinitesimal; consequently any formula in terms of this notation can be converted into the forms appropriate to small strain simply by neglecting powers of a, b, e, f, g, higher than the first.

Strain Ellipse.—The sphere $x^2 + y^2 + z^2 = 1$ is converted into an ellipsoid, which is found by substituting for x, y and z their values in terms of the accented variables. The section of this ellipsoid by the $x\ y$ plane is an ellipse with semi-axes A and B. Its equation is—

$$\left\{(1+f)^2 + a^2\right\}x'^2 - 2\left\{b(1+f) + a(1+e)\right\}x'y' + \left\{(1+e)^2 + b^2\right\}y'^2$$

$$= \left\{(1+e)\,(1+f) - ab\right\}^2. \tag{1}$$

When $b\,(1+f) + a\,(1+e)$ is a positive quantity the major axis of this ellipse makes a positive acute angle with $o\,x$. Well-known properties of the ellipse show that its area is the same as that of the circle—

$$x'^2 + y'^2 = (1+e)\,(1+f) - ab = A\,B, \tag{2}$$

and that the axes may be found from the equation—

$$(A \pm B)^2 = \left\{(1+e) \pm (1+f)\right\}^2 + (a \mp b)^2. \tag{3}$$

* The letters e, f and g are used in the same sense as in Thomson and Tait, Natural Philosophy, but I have not found it convenient to use a and b as they are there employed.

The third axis of the ellipsoid is $C = 1 + g$. If η is the length of any one of the axes, A, B and C are the three roots of the cubic—

$$(\eta - A)(\eta - B)(\eta - C) =$$

$$\left\{ \eta - (1 + g) \right\} \left\{ \eta^2 - \eta \sqrt{(1 + e + 1 + f)^2 + (a - b)^2} + (1 + e)(1 + f) - ab \right\} = 0. \tag{4}$$

The volume assumed after distortion by the unit cube may be called h^3, and—

$$h^3 = A\,B\,C = (1 + g) \left\{ (1 + e)(1 + f) - ab \right\}. \tag{5}$$

Rotation.—The limitations of this discussion imply that the plane of $A\ C$ can only revolve about C, so that the position of this plane is determined when the position of A is known. The angle which A makes with $o\,x$ is, say, ν, and this angle can immediately be inferred from (1) by a well-known formula which gives—

$$\tan 2\nu = -2\,\frac{b(1 + f) + a(1 + e)}{a^2 - b^2 + (1 + f)^2 - (1 + e)^2}.$$

Since the plane $B\ C$ is at right angles to that of $A\ C$, its position follows.

To find the position which the same material lines A and B occupied in the unstrained mass, it is convenient to remember that they must have been at right angles to one another before strain as well as after it; for mere rotation changes no angles, and irrotational strain is by definition a deformation in which the ellipsoidal axes maintain their direction. Hence, if μ was the angle which the fiber A made with $o\,x$ before distortion, its equation was $y/x = \tan \mu$, and by the displacement formulas

$$\tan \nu = \frac{y'}{x'} = \frac{a + (1 + f)\tan \mu}{(1 + e) + b \tan \mu}.$$

The angle which the other axis made before strain was $\mu + 90°$, so that $\tan(\mu + 90°) = -\cot \mu$, while after strain it becomes $\nu + 90°$. Hence—

$$\tan(\nu + 90°) = \frac{a - (1 + f)\cot \mu}{(1 + e) - b \cot \mu} = -\cot \nu.$$

From these two equations ν can at once be eliminated, since $\tan\nu \cot\nu = 1$. Writing out this equation and reducing, one finds—

$$\tan 2\mu = -2\frac{b(1+e)+a(1+f)}{b^2-a^2+(1+f)^2-(1+e)^2}.$$

The equations for ν and μ can be combined to simpler forms. It will be found on trial that the values already deduced lead to—

$$\tan(\nu+\mu) = \frac{a+b}{(1+e)-(1+f)};\quad \tan(\nu-\mu) = \frac{a-b}{(1+e)+(1+f)}. \qquad (6)$$

The angle $\nu - \mu$ is the angle of rotation, so that the condition of no rotation is evidently $a = b$. When the strain is infinitesimal, $a - b$ is infinitesimal, while $1 + e + 1 + f$ approaches 2. Hence $\nu - \mu$ is zero for vanishing strain. If the common limiting value of ν and μ is ν_0, $\tan(\nu + \mu) = \tan 2\nu_0$, or—

$$\tan 2\nu_0 = \frac{a+b}{(1+e)-(1+f)}.$$

Of course this same value is obtained by letting a, b, e and f approach zero in the formulas for $\tan 2\mu$ and $\tan 2\nu$. Thus $\nu - \nu_0 = \nu_0 - \mu$. It is evident that as rotation proceeds new fibers of matter constantly succeed one another in the position of axis, the whole series of fibers in the unstrained mass forming a wedge, $\nu_0 - \mu$ or $\frac{\nu-\mu}{2}$.

Lines of constant Direction.—Lines parallel to $o\,z$ retain their direction relatively to the $x\,y$ plane throughout strain. If the mass were inflexible and subjected to rotation, only these lines would maintain their direction; but when there is strain two other lines may retain their original direction, the two coinciding in the limiting case which separates that of three such lines from that of one.

If $\varkappa$ is the angle which any line in the $x\,y$ plane makes with $o\,x$ before strain and λ the angle which it makes after strain, then—

$$\tan\lambda = \frac{y'}{x'} = \frac{a-(1+f)\tan\varkappa}{1+e+b\tan\varkappa}.$$

If $\lambda = \varkappa$ this gives—

$$\tan\varkappa = \frac{f-e}{2b} \pm \sqrt{\frac{a}{b}+\left(\frac{f-e}{2b}\right)^2}, \qquad (7)$$

which represents two real lines, unless the quantity under the radical

is negative. The two coincide when this quantity is zero, or when $4\,ab + (e - f)^2 = 0$. The value of $tan\ \varkappa$ then reduces to $\pm \sqrt{-a/b}$, showing that a and b must have opposite signs. This particular case occurs in the strain often known as shearing motion, as, for example, when a rivet is shorn by tension of the plates which it connects. It will be discussed later.

The condition of no rotation can be derived from $tan\ \varkappa$. The equation represents two lines, and if $\varkappa_1$ and $\varkappa_2$ are the two angles, $tan\ \varkappa_1\ tan\ \varkappa_2 = -a/b$. If there is no rotation, the axial lines are lines of unchanged direction and $tan\ \varkappa_1\ tan\ \varkappa_2 = -1$, or $a = b$.*

SIMPLE STRAINS.

Pure Rotation.—If the mass undergoes rotation without strain, each of the axes is equal to unity, and h has the same value. Then by (3), $e = f$ and $a + b = 0$, and by (5), $(1 + e)^2 = 1 - a^2$. Hence $tan\ (\nu - \mu) = a/\sqrt{1 - a^2}$, or $sin\ (\nu - \mu) = a$. This result can also be derived immediately from the displacement formulas.

Dilation.—When the only strain is dilation, $A = B = C = h$, whether or not the displacements cause rotation. Then by (3) $e = f$ and $a + b = 0$. By (2) also $(1 + e)^2 + a^2 = (1 + g)^2$. The rotation is then given by—

$$tan\ (\nu - \mu) = \frac{a}{1 + e} = \frac{a}{\sqrt{h^2 - a^2}}.$$

When there is no rotation, so that the displacements cause pure dilation, $a = b = 0$ and $e = f = g = h - 1$.

In dealing with dilations it is usually convenient to consider h, the ratio of dilation, as greater than unity, excepting when its value is unknown. The volume of a compressed mass is then $1/h^3$, which does not vanish unless the ratio of dilation is infinite.

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* The length of the lines of unchanged length exhibits a somewhat remarkable relation. Let k be the length of such a line. Then—

$$\frac{x'}{x} = \frac{y'}{y} = k,$$

and by the displacement formulas—

$$\frac{y}{x} = \frac{k - (1 + e)}{b} = \frac{a}{k - (1 + f)}.$$

This gives—

$$2\,k = 1 + e + 1 + f \pm \sqrt{4\,ab + (e - f)^2}.$$

If k_1 and k_2 are the two values of k, then—

$$k_1\,k_2 = (1 + f)\,(1 + e) - ab,$$

which by (2) is the product of the semi-axes or $A\,B$. Thus the product of these lines remains invariable, whether or not they coincide with the axes.

In any case whatever one may express the axes A and C under the forms $A = h\alpha$, $C = h\beta$ where α and β may be perfectly independent. Then, since $ABC = h^3$, $B = h/\alpha\beta$. The values α, $1/\alpha\beta$ and β are the values which A, B and C would have were there no dilation, and upon the properties of α and β depend those of pure deformation, accompanied by rotation.

Shear.—A shear is the simplest possible deformation. It may be defined as an irrotational strain, unattended by dilation, in which one axis of the strain ellipsoid retains its original length. The unit sphere is thus converted into an ellipsoid, the axes of which are α, 1, $1/\alpha$; and α is called the ratio of shear. It is taken as greater than unity, excepting when it is dealt with as an unknown quantity.

In dealing with shears it is convenient to employ the following abbreviations:*

$$2\,s = \alpha - \alpha^{-1};\ 2\,\sigma = \alpha + \alpha^{-1}.$$

These forms imply that $\sigma^2 - s^2 = 1$.

The displacement formulas for a shear, the contractile axis of which makes an angle ϑ with ox are—

$$x' = x\,(\sigma - s\cos 2\,\vartheta) - ys\sin 2\,\vartheta;\ y' = y\,(\sigma + s\cos 2\,\vartheta) - xs\sin 2\,\vartheta;\ z' = z.$$

To verify this statement consider that $a = b$, so that there is no rotation; $g = 0$ and $(1 + e)\,(1 + f) - ab = 1$, so that there is no dilation; $\tan(\nu + \mu) = \tan 2\,\nu = \tan 2\,\vartheta$, showing that the axes of the strain ellipsoid make angles ϑ and $\vartheta + 90°$ with $o\,x$; finally $b\,(1 + f) + a\,(1 + e)$ is negative, so that the minor axis of the strain ellipsoid makes an acute positive angle with $o\,x$ as required.

When $\vartheta = 90°$ these equations reduce to—

$$x' = x\alpha;\ y' = y\,/\,\alpha;\ z' = z,$$

and when $\vartheta = 45°$, a case of importance,

$$x' = x\sigma - ys;\ y' = y\sigma - xs;\ z' = z.$$

The quantity $2\,s$ is called the *amount* of the shear. There are various aspects of this quantity. One way of looking at it is as the sum of two distortions. The elongation of the major axis is $\alpha - 1$ and the contrac-

* Let $\alpha = \cot \varpi$; then it is easy to see that $\sigma = 1/\sin 2\,\varpi$ and $s = \cot 2\,\varpi$. Here, as will be shown later, $2\,\varpi$ is the acute angle between the circular sections of the strain ellipsoid. The convenience of s and σ depends upon this fact, and the significance of the formulas is increased by bearing it in mind. The quantities s and σ may be regarded as hyperbolic *sine* and hyperbolic *cosine* of an area $\psi = \ln \alpha$; and then $90° - 2\,\varpi$ is the corresponding transcendental angle. This view of the functions, however, is not needful for the purposes of this discussion.

tion of the minor axis is $1 - 1/a$. The sum of the two is $a - a^{-1} = 2s$. While $2s$ measures shear and is not unfitly called the amount of shear, s might equally well have been regarded as the measure of shear; indeed, this would have been more convenient, because it would have accorded with the received nomenclature of stresses.

Many of the properties of shear can be inferred in the simplest manner from its definition. Since it involves neither change of volume nor of the area of the strain ellipse, it can consist only in re-arrangement of matter, each fiber perpendicular to the plane of shear, retaining its original thickness, length and direction, though shifted to a new position. Since the major axis of the shear ellipse exceeds unity and the minor axis falls short of unity, there must be four intermediate radii of unit length, and the symmetry of the conditions shows that these four radii form two diameters. Thus there are two diameters which have the same length after strain as before strain. These diameters are the traces on the $x\,y$ plane of planes passing through $o\,z$, and these planes undergo no distortion through strain. In them the circular sections of the strain ellipsoid evidently lie. All planes parallel to these are also, by the properties of homogeneous strain, planes of no distortion. Any two planes of no distortion must stand at the same perpendicular distance apart after strain as before, for were it otherwise the volume of the ellipsoid would be changed.

Thus a shear can consist only in the sliding of planes of no distortion upon one another and in changes of the angles between the two systems of undistorted planes.

The behavior during the straining process of the planes of no distortion is of great geological importance; but as this behavior depends to some extent upon rotation, it appears appropriate to defer its discussion until some of the simpler compound strains have been explained.

COMPOUND STRAINS.

How treated.—For the immediate purposes of this paper it is needful to examine compound strains of several varieties. It seems desirable also to examine the simpler combinations in somewhat more detail than is absolutely essential to the results which will be deduced from them in the subsequent sections in order to give assurance that the geological deductions are not vitiated by the omission of important properties of strain. It is to be hoped also that the treatment here submitted may facilitate the solution of geological problems not touched upon in the present investigation.

Pure Deformation.—Any pure deformation is resoluble into two shears at right angles to one another, one axis being common to the two ele-

mentary strains. This will be demonstrated by a proof that any relation whatever between the axes A, B and C of the ellipsoid whose volume is proportional to h^3 can be brought about by two such shears. Let $A = h\alpha$, $B = h\gamma$, and let $C = h\beta$, where A and B are entirely arbitrary. Then since $ABC = h^3 = Bh^2\alpha\beta$, it is evident that $1 / \alpha\beta = \gamma$, or $B = h / \alpha\beta$. Now, if a shear of ratio α is applied axially in the $x\,y$ plane to the sphere, $x^2 + y^2 + z^2 = h^2$, it will reduce this mass to the ellipsoid $x^2 / \alpha^2 + y^2\alpha^2 + z^2 = h^2$. If a second shear of ratio β is applied axially in the $y\,z$ plane it will further reduce the second axis in the ratio β and elongate the third axis in the same ratio. Thus the two shears yield an ellipsoid $x^2 / \alpha^2 + y^2\alpha^2\beta^2 + z^2 / \beta^2 = h^2$, and the axes of this ellipsoid are $h\alpha$, $h / \alpha\beta$ and $h\beta$, or A, B and C.

A converse proposition is also important. Any number of shears applied axially to a sphere can only modify the relations of the axes to values A, B and C, the volume of the mass remaining proportional to $ABC = h^3$. Hence any number of axial shears are reducible to two and not to three, as one might be inclined to surmise. This resolution may take place mathematically with any one of the axes as the common axis of the two shears. In most cases, however, considerations of symmetry point to one of the axes as that common to the two shears.

A simple shear produces relative motion of particles or fibers only in its own plane. Its only effect on fibers in planes at right angles to its own is to elongate them uniformly in one direction without any tendency to the causation of relative motion. Hence the effects of each shear must be considered in its own plane, and the relative motion produced by each of two shears in orthogonal planes is independent.

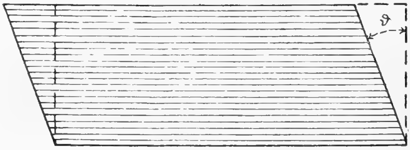

FIGURE 1.—*Scission.*

Shearing Motion or Scission.—A "shearing motion" is the rather ill-chosen designation of a strain nearly corresponding to that which occurs when a bar or plate is shorn by a pair of shears, or when a rivet yields perpendicularly to its axis, say, in a bursting boiler. The term is not happy, because it seems to indicate that there are shears not accompanied by motion. It is, of course, from this strain that the term shear was de-

rived, but this has been transferred to the simpler deformation. The name *scission* would aptly indicate the "shearing-motion" strain, which consists in the relative movement of undistorted material planes, each sheet of infinitesimal thickness remaining in its own mathematical plane, as shown in figure 1. The motion can be well illustrated with a pack of cards.

Scission or shearing motion is that case of strain already referred to in which there is a single line of unchanged direction in the $x\,y$ plane, and it consists of a simple shear compounded with a rotation of the axes of the strain ellipsoid.

The most important case of scission is that in which the direction of the planes of constant direction and no distortion coincide with one of the axes. If this axis is $o\,x$ the displacement formulas may be written simply—

$$x' = x - 2\,ys;\; y' = y.^*$$

Here $2\,s = a - a^{-1}$, the amount of the shear involved. The rotation is given by—

$$tan\,(\nu - \mu) = s;$$

and since $tan\,2\,\nu_0 = tan\,(\nu + \mu) = \infty$, the axes of the ellipse at the inception of strain were at 45° to the fixed axes. The quantity $4\,ab + (e - f)^2$ becomes zero by the simultaneous disappearance of its two terms. If ϑ is the angle by which a line originally parallel to $o\,y$ is deflected by the strain,

$$tan\,\vartheta = b = 2s,$$

so that the amount of shear may be defined as "The relative motion per unit distance between planes of no distortion." †

Two Shears in the same Plane.—The most frequent combination of two shears in the same plane is that in which the axes of one of these strains makes angles of 45° with those of the other. If the contractile axis of one of the shears makes an angle of 45° with $o\,x$, displacing x to x' and y to y', the ratio of shear being a, and if the contractile axis of the other

* If the planes of constant direction and no distortion make an angle, ϕ, with $o\,x$, the displacements are given by—

$$x' = x\,(1 + s\,sin\,2\,\phi) - ys\,(1 + cos\,2\,\phi);\; y' = y\,(1 - s\,sin\,2\,\phi) + x\,s\,(1 - cos\,2\,\phi).$$

The product, $a\,b = - s^2\,sin^2\,2\,\phi$, is an essentially negative quantity. Hence the signs of a and b are necessarily different. Compare the discussion of formula (7).

† Thomson and Tait, Nat. Phil., sec. 175.

shear coincides with $o\,y$, displacing x' to x'' and y' to y'', the ratio being a_1, then the displacement formulas* are—

$$x'' = x'a_1 = xa_1\sigma - ya_1 s\,;\; y'' = \frac{y'}{a_1} = \frac{y\sigma}{a_1} - \frac{xs}{a_1}.$$

This strain, although the resultant of two irrotational strains, is rotational, since $a - b$ is not zero. It is easy to see that this would probably be the case, for the first shear alters the direction of every line excepting those coinciding with its axes, and the direction of these is changed by the second shear. The rotation is given by—

$$tan\,(\nu - \mu) = ss_1 \,/\, \sigma\sigma_1,$$

where $2\,\sigma_1 = a_1 + a_1^{-1}$ and $2\,s_1 = a_1 - a_1^{-1}$.

It is an important fact that when the shears are of infinitesimal amount this combination becomes irrotational. When a and a_1 differ infinitesimally from unity, $s = e$, $s_1 = e_1$, $\sigma = 1$, $\sigma_1 = 1$ and $tan\,(\nu - \mu) = ee_1$, an infinitesimal of the second order.†

The two finite shears are equivalent to the rotation stated above and a simple shear of amount—

$$2\sqrt{\sigma^2 s_1^2 + \sigma_1^2 s^2}.$$

Plane undilational Strain.—The most general strain treated in this paper may be considered as a perfectly general undilational strain in one plane, combined with a shear at right angles to this plane and a dilation. The more complex effects are confined to the principal plane in which rotation occurs, and it is therefore desirable to reduce the plane undilational strain to its simplest terms.

One method of resolution consists in regarding the general strain as compounded of elementary strains symmetrically oriented with reference to the fixed axes, namely, an axial shear; a shear at 45° to $o\,x$; and a scission, the unchanged direction of which coincides with one of the axes.

It is somewhat easier to test the results of analysis in this case than to

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* When the first shear makes an angle ϑ with $o\,x$ the formulas are—

$$x'' = xa_1\,(\sigma - s\,cos\,2\,\vartheta) - ya_1 s\,sin\,2\,\vartheta\,;\; y'' = \frac{y}{a_1}\,(\sigma + s\,cos\,2\,\vartheta) - \frac{x}{a_1}\,s\,sin\,2\,\vartheta.$$

Here $ab = s^2\,sin^2\,2\,\vartheta$, and is essentially positive.

†When the shears make an angle ϑ and the strain is infinitesimal, $tan\,(\nu - \mu) = ee_1\,sin\,2\,\vartheta$, which is also an infinitesimal of the second order, so that any two shears, and therefore any number of shears of infinitesimal amount, combine to an irrotational strain.

analyze the general strain. To begin with, changes of notation are convenient. The expression—

$$-2a(1+e) \pm \sqrt{1+4a^2(1+e)^2}$$

represents two values, one of which is minus the reciprocal of the other. Let the positive value be $a_2^{\,2}$, so that the negative value is $-a_2^{-2}$. Then, if $2\sigma_2 = a_2 + a_2^{-1}$ and $2s_2 = a_2 - a_2^{-1}$, it is easy to see that—

$$-a(1+e) = \sigma_2 s_2.$$

Call the value of s_2/a minus a_3. Then—

$$a = -\frac{s_2}{a_3} \text{ and } 1+e = \sigma_2 a_3;$$

and if one denotes—

$$\frac{a_3(1+f)-\sigma_2}{2\,s_2} \text{ by } s_1,$$

$$1+f = \frac{\sigma_2 + 2\,s_2 s_1}{a_3}.$$

Thus far only changes of notation have been introduced. To find the value of b in terms of this notation and for this case, consider that the sole condition of plane undilational strain is the invariability of the area of the strain ellipse. This is expressed by—

$$(1+e)(1+f) - ab = 1 \text{ or } b = \frac{(1+e)(1+f)-1}{a}.$$

Introducing the new notation into this expression—

$$b = -a_3(2\,s_1\sigma_2 + s_2).$$

To interpret these values, suppose the final position of x and y to be x''' and y''', so that—

$$x''' = (1+e)x + by = a_3\left\{(x - 2\,s_1 y)\,\sigma_2 - y s_2\right\};$$

$$y''' = (1+f)\,y + ax = \frac{y\sigma_2}{a_3} - \frac{x - 2\,s_1 y}{a_3}\,s_2.$$

This evidently expresses a simple axial shear of ratio a_3 combined with a compound strain. If x'' and y'' are the displacement values for this last—

$$x'' = (x - 2\,s_1 y)\,\sigma_2 - y s_2;\; y'' = y\sigma_2 - (x - 2\,y s_1)\,s_2.$$

By substituting $x' = x - 2\,s_1 y$ and $y' = y$ these become the equations of a simple shear at an angle of 45° to $o\,x$. Finally—

$$x' = x - 2\,s_1 y, \quad y' = y,$$

are the equations of a simple scission.

Thus the most general plane undilational strain is resoluble into an axial shear, a shear at 45° to $o\,x$, and a scission in the direction of one of the axes.

When $a = b$ this general strain reduces to a single shear. If $b / a = (1 + e) / (1 + f) = \alpha_3^2$ the strain reduces to two shears or, in other words, the scission vanishes. If $a = 0$ and $(1 + e) / (1 + f) = \alpha_3^2$ the strain is an axial shear combined with a scission.*

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* *A second Resolution.*—The above method of resolution is the most convenient for computation, but it fails to disclose a relation of much geological significance. It is a fact that any plane undilational strain is resoluble either into two shears at an angle ϑ or into a shear and a scission at an angle ϕ The significant difference between these two combinations is that the two shears cause a relatively small rotation which is an infinitesimal of the second order when the strain is infinitesimal, while the shear and scission produce a large rotation which is of the same order as the strain when this is infinitesimal. The criterion discriminating the two classes of strains is exceedingly simple. When a and b have the same sign the strain is invariably equivalent to two shears. When a and b have opposite signs the strain is invariably equivalent to a shear and a scission. As in the case of the other resolution, it is easiest to discriminate changes of notation from equations of condition synthetically.

Let a and b have the same sign. Then to show that the strain is compounded of two shears one may proceed as follows: Adopt the notation—

$$\sigma_2 = \frac{b\,(1+f) + a\,(1+e)}{2\sqrt{ab}}; \quad \sin 2\,\vartheta = \frac{-\sqrt{ba}}{s_2}; \quad \alpha_3^2 = \frac{b}{a}.$$

Each of these expressions is possible whenever a and b have the same signs, and then only. In addition, the condition of plane undilational strain is $(1+e)\,(1+f) - ab = 1$. Here, then, is a number of equations just sufficient to determine a, b, e and f. Remembering that $1+e$ and $1+f$ are necessarily positive, they give—

$$a = \frac{s_2 \sin 2\,\vartheta}{\alpha_3}; \quad b = -\,\alpha_3 s_2 \sin 2\,\vartheta; \quad 1+e = \alpha_3\,(\sigma_2 - s_2 \cos 2\,\vartheta); \quad 1+f = \frac{\sigma_2 + s_2 \cos 2\,\vartheta}{\alpha_3}.$$

Is is easily seen that these values answer to an axial shear of ratio α_3 and a second shear of ratio α_2 at an angle ϑ with $o\,x$.

Let a and b have opposite signs. This is implied in the expression—

$$\alpha_3 = \frac{1 \pm \sqrt{-ab}}{(1+f)},$$

and the condition of plane undilational strain is $(1+e)\,(1+f) - ab = 1$. Purely notative are the following:

$$2\,s_1 = \alpha_3\,a - \frac{b}{\alpha_3}; \quad \sin 2\,\phi = \frac{1+e-\alpha_3}{\alpha_3\,s_1}.$$

These four equations give—

$$a = s_1 \frac{(1 \pm \cos 2\,\phi)}{\alpha_3}; \quad b = \mp\,\alpha_3 s_1\,(1 \mp \cos 2\,\phi); \quad 1+e = \alpha_3\,(1 \pm s_1 \sin 2\,\phi); \quad 1+f = \frac{1 \mp s_1 \sin 2\,\phi}{\alpha_3}.$$

These values answer to an axial shear of ratio α_3 and a scission of ratio α_1. The direction of the scission makes an angle ϕ with $o\,x$ if the given values of a and b are satisfied by choosing the upper sign in these expressions. In the opposite case the direction of the scission makes an angle ϕ with $o\,y$.

The foregoing synthesis shows how a plane undilational strain may be resolved when the displacements are given. Cases also arise in which it is desirable to find the displacements a, b, e and f from a known shear and values of ν and μ. If the ratio of the shear is α, the values of σ and s can be derived from it, and these two values, together with the values of $\nu + \mu$ and $\nu - \mu$ constitute four equations from which a, b, e and f can be deduced. They give—

$$a = s \sin(\nu + \mu) + \sigma \sin(\nu - \mu)\,;\ 1 + e = \cos(\nu - \mu) + s \cos(\nu + \mu)\,;$$

$$b = s \sin(\nu + \mu) - \sigma \sin(\nu - \mu)\,;\ 1 + f = \cos(\nu - \mu) - s \cos(\nu + \mu). \quad (8)$$

These values, substituted in the formulas of preceding paragraphs, show to what simplest strain system a given rotation and shear are referable.

Strain due to Pressure.—For the sake of keeping the discussion of strains together, it may be assumed here by anticipation that a pressure produces a cubical compression of ratio h* and two equal shears of ratio α at right angles to one another. For brevity, let—

$$2\,t = \alpha - \alpha^{-2}\,;\ 2\,\tau = \alpha + \alpha^{-2}.$$

Then the displacement formulas for a strain due to a pressure in the direction ϑ are—

$$x' = \frac{x}{h}(\tau - t \cos 2\,\vartheta) - \frac{y}{h} t \sin 2\,\vartheta\,;\ y' = \frac{y}{h}(\tau + t \cos 2\,\vartheta) - \frac{x}{h} t \sin 2\,\vartheta\,;$$

$$z' = \frac{z}{h}(\tau + t).$$

It will be observed that these formulas are analogous to those for simple shear.

When the pressure is vertical, so that $\vartheta = 90°$,

$$x' = \frac{x\alpha}{h}\,;\ y' = \frac{y}{\alpha^2 h}\,;\ z' = \frac{z\alpha}{h}.$$

If a vertical strain of this kind is combined with a scission or shearing motion in a horizontal direction, the values of x only will be modified by the second strain. If x'' is the final value of x and $2\,s_1$ is the amount of the shear produced by the scission—

$$x'' = \frac{x\alpha}{h} - \frac{2\,y s_1}{\alpha^2 h}\,;\ y'' = y'\,;\ z'' = z'\,;\ \text{and } \tan(\nu - \mu) = \frac{s_1}{\tau}(\tau - t).$$

*Here h is taken greater than unity, and is the reciprocal of the value which in a given case would satisfy (5).

Here the rotation is of the same order as the strain and is not negligible when the strain is small.

If the strain produced by vertical pressure is combined with a shear at 45°, the value of z will be unchanged. If σ_2 and s_2 are the values of σ and s for this added shear, and if x''' and y''' are the final displacements for this case—

$$x''' = \frac{x a \sigma_2}{h} - \frac{y s_2}{a^2 h}; \quad y''' = \frac{y \sigma_2}{a^2 h} - \frac{x a s_2}{h}; \quad z''' = z'; \quad tan\ (\nu - \mu) = \frac{s_2 t}{\sigma_2 \tau}.$$

In this case, when the strain is infinitesimal, the rotation is an infinitesimal of the second order.

Elongation.—Simple elongation (unattended by changes in the area of the section perpendicular to the direction of elongation) is sometimes regarded as a simple strain. It may as well or better be considered as compounded of two shears and a dilation. In discussing dilation it was pointed out that the three axes of the strain ellipsoid may be written $A = h\alpha$, $B = h / \alpha\beta$, $C = h\beta$. When the strain is simple elongation in the direction of B, $h\alpha = 1$, $h\beta = 1$ and $B = h^3 / AC = h^3$. Thus elongation consists of two shears each of ratio h and a cubical dilation h.

In the case of contraction or negative elongation a value h_1 is to be substituted for h and $h_1 = 1 / h$. Thus contraction is compounded of cubical compression $1 / h$ and two shears. If h is the same in the two cases, the same shears are involved in each strain but differently combined. In elongation the tensile axes of the shears coincide, while in contraction the contractile axes coincide.

The same two shears which without dilation would stretch a mass to an infinite length, when differently combined would reduce it to an infinitesimal thickness without cubical compression.

PLANES OF MAXIMUM TAGENTIAL STRAIN.

Position of undistorted Planes.—Attention has already been called to the fact that in a simple shear the circular sections of the strain ellipsoid are undistorted planes parallel to which relative motion takes place, and further inquiry into them is essential to a full elucidation of this strain. In the other plane undilational strains there are similar planes, though their behavior is modified in essential respects. In tri-dimensional strain the corresponding planes are no longer undistorted, but nevertheless influence the character of the deformation. It seems most logical to begin with a discussion of the case of simple shear and afterwards to modify the results for complex strains.

The circular sections of the shear ellipsoid for which the ratio is a make an angle with the major axis whose cotangent is a.* If this angle is called ϖ, the amount of shear is—

$$2s = a - a^{-1} = cot\, \varpi - tan\, \varpi = 2\, cot\, 2\,\varpi = 2\, tan\, (90^\circ - 2\,\varpi).$$

Here s, or half the so-called amount of shear, appears as measured by the divergence from 90° of the angle $2\,\varpi$ between the circular sections of the shear ellipsoid. A right angle is the value which $2\,\varpi$ assumes when the strain is infinitesimal.

The original position of the particles constituting the planes of no distortion, relatively to the fibers which coincide with the axes of the ellipse, bears a simple relation to ϖ. Suppose the shear to be axial and that the sphere $x_1^2 + y_1^2 + z_1^2 = h^2$ is converted into the ellipsoid $x^2 / a^2 + y^2 a^2 + z^2 = h^2$, so that $y_1 / x_1 = a^2 y / x$; then the original position of the material plane forming the circular section of the shear ellipsoid was $a^2\, tan\, \varpi = a = tan\, (90^\circ - \varpi)$.

Thus these material planes made before shear the same angle with the minor axis of the ellipsoid which they make after strain with the major axis.

Planes of maximum Strain.—It is instructive to regard the planes of no distortion from another point of view. Consider any two very thin plane layers in the unstrained mass which include between them the axis $o\,z$, and let the angle which they make with $o\,x$ be φ. After strain these planes will still be planes; they will make an angle φ' with $o\,x$ and $tan\, \varphi = a^2\, tan\, \varphi'$ or

$$tan\, (\varphi - \varphi') = \frac{(a^2 - 1)\, tan\, \varphi}{a^2 + tan^2\, \varphi}.$$

The greater the angle $\varphi - \varphi'$ becomes, the greater must be the tangential strain. Now this angle and its tangent are greatest when $tan\, \varphi = a$ or when $tan\, \varphi' = 1 / a = tan\, \varpi$. Thus the undistorted planes are those for which tangential strain is a maximum. For the axes, on the other hand, $\varphi - \varphi' = 0$, and there is no tangential strain.

Angular Range of undistorted Planes.—Though at the end of a shear or other plane strain there are planes which have the same dimensions as before strain, it is not true that these planes have undergone no distortion. On the contrary, there is but one strain in which any lines escape

* The intersections of the shear ellipse with the circle of equal area are points in these sections, since the radii of the ellipse retain their original length, say unity. These intersections are given by—

$$\frac{x^2}{a^2} + a^2 y^2 = 1 = x^2 + y^2,$$

whence $a = \pm x / y$.

temporary distortion. In general, the circular sections of the shear ellipsoid consist of different particles when the strain begins from those which occupy the circular sections when the strain ends. In other words, these geometrical planes sweep through a certain angle, coinciding successively with all the particles in a wedge of the mass bounded by limiting material planes. Futhermore, one of the circular sections sweeps in general through a different angle from that over which the other ranges, so that the rate of movement relatively to the particles is different. This difference of rate is a matter of much importance when the mass possesses viscosity, as all real matter seems to do.

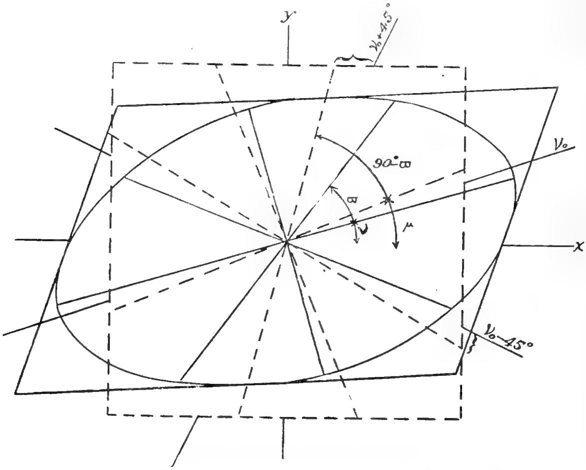

FIGURE 2.—*Range of circular Sections.*

The square of broken lines is strained to the rhomb in full lines. The full lines intersecting at the center are the final axes and lines of no distortion. The broken lines intersecting at the center show the positions which these same lines occupied before strain. The lines ν_0 and $\nu_0 \pm 45°$, which are drawn only to the outside of the square, indicate the position of the fibers which at the inception of strain coincided with the major axis and the lines of no distortion. The { { mark the wedges in the unstrained solid over which the geometrical planes of no distortion sweep. For the displacements see example, p. 34.

The range of the circular sections must therefore be determined, and it is most easily discussed by examining in the unstrained mass the limiting angles between which the circular sections will vary when strain of assigned amount takes place. The general formulas afford the means for such a determination.

When strain begins the major axis of the shear ellipse makes an angle, ν_0, with $o\,x$, and the undistorted planes then make an angle of 45° with the major axis or angles $\nu_0 \pm 45°$ with $o\,x$. When the strain is complete the major axis makes an angle, ν, with $o\,x$, and the undistorted planes make angles ϖ with this axis. But before strain began this last axial fiber made an angle, μ, with $o\,x$, and the particles constituting the last undistorted plane then made an angle, $90° - \varpi$, with μ. Thus in the undistorted mass the angles bounding the wedge through which the circular sections will sweep are $\nu_0 \pm 45°$ and $\mu \pm (90° - \varpi)$.

On the side of the minor axis toward which rotation takes place this range is therefore—

$$\nu_0 + 45° - \left\{ \mu + 90° - \varpi \right\} = \varpi - 45° + \frac{\nu - \mu}{2},$$

and on the opposite side of the minor axis the range is—

$$\left\{ \mu - (90° - \varpi) \right\} - (\nu_0 - 45°) = \varpi - 45° - \frac{\nu - \mu}{2}.$$

The difference of range is thus the angle of rotation, and is actual whenever the strain is a rotational one.

In a simple shear, then, there is no difference in range, and the range on each side is $\varpi - 45°$. In the case of scission or shearing motion it is easy to see that $2\,(\varpi - 45°) = \nu - \mu$, so that the range is zero on the side from which rotation takes place, and one and the same set of fibers are exposed to maximum tangential strain throughout the process of strain, while the other circular section sweeps through the maximum possible angle. In any case of plane strain the difference in range is at once assigned by the angle of rotation, so that for two shears in the same plane at an angle of 45° the difference is measured by $tan\,(\nu - \mu) = ss_1/\sigma\sigma_1$.

For plane strains the value of ϖ may be simply expressed in terms of the displacement coëfficients. It is easy to see that—

$$\frac{1}{a^2} = tan^2\,\varpi = B/A.$$

Hence also—

$$tan^2\,2\,\varpi = \frac{4\,AB}{(A - B)^2} = 4\,\frac{(1 + e)\,(1 + f) - ab}{(e - f)^2 + (a + b)^2}. \qquad (9)$$

Case of Strain in three Dimensions.—It has been pointed out already that the relative motions of the particles in the $x\,y$ plane due to a shear α are unaffected by an axial shear β in the $B\,C$ plane. The sole effect of the second shear, so far as the $x\,y$ plane is concerned, is to change the length of all lines parallel to the common axis of the shears uniformly in

the ratio β. Hence if before the imposition of the β shear a line made an angle ϖ with A, this shear will alter the angle ϖ to, say, ω, and—

$$tan\ \omega = \beta^{-1}\ tan\ \varpi = 1 / \alpha\beta = B / h. \qquad (10)$$

Lines making the angle ω with A will not be undistorted when β differs from unity, but they will be lines of maximum tangential strain whatever may be the value of β.

The value of ω cannot easily be determined immediately from the displacement coëfficients. It can be expressed in terms of the axes for $tan^3\ \omega = B^2 / AC$, but the value of B / C is a complicated one, on account of the inclination of the plane $B\ C$.

Rotation is supposed to be confined to the axis $o\ z$, and is therefore unaffected by the shear β. Hence for strain in three dimensions, as well as in plane strain, the difference of range of the planes of maximum strain measured in the unstrained solid is the angle of rotation, $\nu - \mu$.

Numerical Example of Strain.—The application of the formulas developed may be illustrated by an example. Let—

$$a = 0.1;\ b = 0.3;\ 1 + e = 1.2;\ 1 + f = 0.7;\ 1 + g = 1.1.$$

This is a rotational strain, since $b > a$. Equations (6) also show that $\nu + \mu = 38° 40'$ and $\nu - \mu = -6° 1'$. If the displacements constituted a pure rotation, $sin\ (\nu - \mu)$ would equal a. As this is not the case, there is strain. Formula (5) gives $h = 0.962$, so that the strain is a compressive one. If deformation were confined to the $x\ y$ plane, $1 + g$ would equal h. Hence there are two shears. To find them it is most convenient to determine the axes of the ellipsoid from (3), which gives $A = 1.275$, $B = 0.635$, $C = 1.1$. Then also $\alpha = A / h = 1.325$, $\beta = C / h = 1.143$. Equation (1) shows that the major axis makes a positive acute angle with $o\ x$. The rotation, dilation and the ratios of the two shears are now known.

To resolve the rotation and the α shear into component, plane, undilational strains, let a_1, b_1, e_1 and f_1 be the displacements which would produce only the α shear and the rotation. Then formula (8) leads to these values—

$$a_1 = 0.0695;\ b_1 = 0.2872;\ 1 + e_1 = 1.2572;\ 1 + f_1 = 0.8113,$$

which give for the elementary plane strains—

$$\alpha_2 = 0.9168;\ \alpha_3 = 1.2524;\ s_1 = 0.0708.$$

The α shear with the rotation is therefore equivalent to a shear with its contractile axis coinciding with $o\ y$ of ratio 1.2524, together with a shear the *tensile* axis of which makes a positive angle of 45° with $o\ x$, its ratio

being $1/\alpha_2 = 1.0908$; and lastly, a scission for which $s_1 = 0.0708$. Since a_1 and b_1 have the same sign, the plane undilational strain might have been regarded as due to the combination of two shears without any scission, but these shears would not be at 45° to one another.

The value of ϖ is given by $tan\ \varpi = 1/\alpha = 0.7545$, so that $\varpi = 37° 2'$. Had only a_1, b_1, e_1 and f_1 been given, ϖ could have been obtained from (9), which, of course, gives the same angle.

The first fiber to occupy the position of major axis at the inception of strain made an angle with $o\,x$, which was $\nu_0 = (\nu + \mu)/2 = 19° 20'$, and at this same time the positions of the lines of maximum strain were at $\nu \pm 45°$; *i. e.*, at 64° 20′ or — 25° 40′. The original position of the fiber which eventually constitutes the final major axis was at an angle μ or 20° 20½′ to $o\,x$. The original position of the fibers which at the end of the strain undergo maximum strain was at $\mu \pm (90° - \varpi)$; *i. e.*, 75° 18½′ and — 30° 37½′. The angles in the unstrained mass bounding the fibers which subsequently undergo maximum strain on the side from which rotation takes place are thus, $\mu + 90° - \varpi$ and $\nu_0 + 45°$, and these differ by 10° 58½′. On the other side the limiting angles are $\nu_0 - 45°$ and $\mu - (90° - \varpi)$, which differ by only 4° 57½′. Thus the fibers on the positive side of the major axis pass through the condition of maximum strain more than twice as rapidly as do those on the negative side of the major axis. If the resistance which the mass offers to deformation varies with the rapidity of deformation (as is the case with real substances), this difference will somewhat affect the results. Had a and b different signs, this difference would be far greater.

The angle ω for this example is by formula (10) 33° 25′, so that the β shear changes the direction of the lines of maximum strain by some 3½ degrees, though without tending to produce any further relative motion upon them.

Figure 2 is drawn for the displacements a_1, b_1, e_1 and f_1, and illustrates the range of planes of maximum strain for this example.

Finite Stress.

RELATIONS OF STRESS AND STRAIN.

In the foregoing discussion the geometrical properties of homogeneous strain due to given displacements as exhibited on any principal plane of a strain ellipsoid have been developed, and I am aware of no important property of such strain which has been omitted. If the relations of displacement to stress (or force per unit area) could be as fully developed, we should have a substantial basis for a theory of finite distortion, since however heterogeneous a strain may be, any infinitesimal portion of the mass is homogeneously strained.

The relations between finite stress and displacement lack satisfactory experimental basis and cannot therefore be fully developed, but it is desirable to show just where knowledge ends and ignorance begins.

Stresses in a Shear.—From the discussion of the properties of shear, it follows that the undistorted planes are necessarily subjected to purely tangential stresses; for they are neither elongated nor drawn apart during strain, while normal forces acting upon them would produce such effects.

The stress phenomena in a shear can be examined as a case of equilibrium, and such an examination reveals the somewhat important fact that the planes of maximum tangential stress do not coincide with the planes of maximum tangential strain.* It also teaches how the two component forces involved in a finite shear are related, and thus, in spite of ignorance of the direct relations between stress and strain, the inquiry is by no means fruitless.

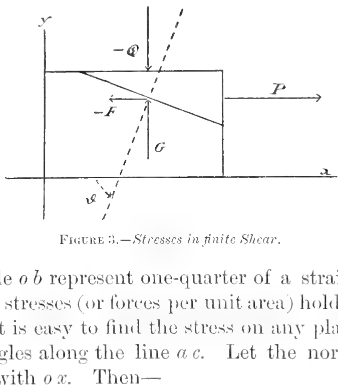

FIGURE 3.—*Stresses in finite Shear.*

Let the rectangle $o\,b$ represent one-quarter of a strained cube and let $-Q$ and P be the stresses (or forces per unit area) holding it in this state of strain. Then it is easy to find the stress on any plane cutting the $x\,y$ plane at right angles along the line $a\,c$. Let the normal to the plane make an angle ϑ with $o\,x$. Then—

$$ab = ac \sin\vartheta; \quad bc = ac \cos\vartheta.$$

If F and G are the component stresses on $a\,c$ parallel to $o\,x$ and $o\,y$, these components must hold the stresses on $a\,b$ and $a\,c$ in equilibrium. Now, the total force on $a\,c$ in the direction of $o\,x$ is $-F\,a\,c$ and the whole force on $b\,c$ is $P\,b\,c$. Q and G are similarly related, so that—

$$-Fac = Pbc = Pac\cos\vartheta,$$

$$Gac = -Qab = -Qac\sin\vartheta,$$

or—

$$-F = P\cos\vartheta; \quad G = -Q\sin\vartheta.$$

---

* In at least some treatises on elasticity and geological mechanics it seems to have been assumed that these planes do coincide.

The position of the plane remaining constant, it is permissible to combine F and G like simple forces to a tangential component, T, acting in the direction of $a\,c$, and a normal component, N, acting perpendicularly across $a\,c$. Evidently, if P and Q are considered as in general positive quantities—

$$T = -F \sin\vartheta - G \cos\vartheta = (P + Q) \sin\vartheta \cos\vartheta,$$

$$N = -F \cos\vartheta - G \sin\vartheta = P \cos^2\vartheta + Q \sin^2\vartheta,$$

and T will be a maximum with reference to ϑ when—

$$\cos^2\vartheta = \sin^2\vartheta \text{ or } \vartheta = \pm 45°.$$

Although the tangential stress is greatest for this angle, one has no right to infer that the maximum tangential strain is at 45°, because there is a normal stress on the plane at this angle amounting to $(P + Q)/2$. On the contrary, it was shown above (page 34) that the maximum tangential strain in a shear occurs for planes which make an angle with $o\,x$ the tangent of which is $1/a$, or the normal to which is given by $\tan\vartheta = a$. The conditions of this plane are also such that there can be no normal stress acting upon it, and hence $N = 0$, so that one of the stresses must have a negative value and—

$$\tan^2\vartheta = \frac{P}{-Q} = a^2.$$

This relation enables one to determine the forces which produce a finite shear. The area on which the stress Q acts is a, and the force acting on the distorted cube in this direction is minus $Q\,a$. The area on which P acts is $1/a$, and the lateral force is therefore P/a; but by the last equation $-Q\,a = P/a$, so that a finite shear, as well as an infinitesimal one, results from the action of two equal forces acting at right angles to one another in opposite senses.*

Simple Pressure.—Knowing the composition of a shear enables one to pass synthetically to the case of simple pressure or traction. If two equal shears at right angles to one another are combined, the contractile axes coinciding, each must produce the same effect as the other if the mass is isotropic. Each must also produce the same effect as if it acted alone. This statement does not imply a relation between stress and strain, for the shear in the $x\,y$ plane leaves the mass unstrained in the $y\,z$ plane. Hence two equal shears, each of ratio a, reduce the unit cube

* I have met with no demonstration of this relation between finite shearing stress and strain, but I am not prepared to state that none has been published.

to a thickness $1/a^2$ any of the sides of the mass having a length a. The upper surface has an area a^2 and the side an area $1/a$.

The tensile stress on sides of the mass is P in each direction, so that the two tensile forces are each P/a. When only one shear acted on the mass the contractile stress was Q, but the second shear increased each unit area to a, so that the contractile stress of the first shear was thereby reduced to Q/a. The stress due to the second shear is of precisely the same amount, so that the total contractile stress becomes $2\,Q/a$ on an area a^2. Thus the total force acting on this surface is $2\,Q\,a$, which, as has been shown, is equal to $2\,P/a$ in absolute value.

Let the mass thus strained be subjected to an hydrostatic pressure equal to P/a. Then the tensile forces would be balanced and the pressure on the upper surface would become $3\,Q\,a$.

Thus, two equal shears combined with an hydrostatic pressure equal to either component of either shear, applied to the unit cube, reduce to a simple pressure acting on one surface of the cube. Had the shears been so combined that their tensile axes coincided, a dilational stress equal to either component of either shear would have been needful to reduce the system to a simple traction.

Conversely, it is evident that a finite traction or pressure is resoluble into a dilational stress (positive or negative) and two shearing stresses, just one-third of the force being employed in each of the three component stresses. It is well known that precisely this resolution takes place for infinitesimal tractions, but the analysis of such tractions is usually stated as if the conclusions were true only for the limiting case of infinitesimal forces.

These results seem to exhaust what can be known of the relations of finite stress and strain without a further knowledge of the actual value of a in terms of Q. No two different pressures or different shears or dilations can be compared without a law relating to stress and strain.

Meaning of Hooke's Law.—It was to fill this gap that the famous law of Hooke was proposed. This is *Ut tensio sic vis*, which is now translated, Strain is proportional to stress. The brevity of Hooke's law has often been admired. The fact is that it is too brief fully to express the meaning really attached to it. It does not appear in this form of the law whether the stress (or pressure per unit area) is to be reckoned for the solid in an unstrained state or after the mass has reached a condition of equilibrium under the action of the external forces tending to deform it. But since the purpose of the mathematical theory of elasticity is to find equations expressing equilibrium of elastic masses, it is clear that this equilibrium must be supposed established before one can reason on the system of stresses which will maintain it. As a matter of fact, the funda-

mental equations are always derived in this way, and the stress is taken primarily as the force per unit area of the mass in a state of equilibrium. Thus, a less ambiguous statement of this law would be: Stress in an elastic mass which has reached a condition of equilibrium is proportional to the strain which the mass has undergone.

It is a curious fact that this is not the law which Hooke intended to express. Hooke's words are, "*Ut tensio sic vis:* That is, the Power of any Spring is in the same proportion with the tension thereof: That is, if one power stretch or bend it one space, two will bend it two, and three will bend it three, and so forward."* Thus Hooke's law as he meant it is clearly *load* is proportional to strain, and he had no idea of confining his law to infinitesimal deformations.

When the stresses and strains are infinitesimal it is easy to show that the two assertions, *stress* is proportional to strain and *load* is proportional to strain, are really equivalent; but for finite deformations they lead to very different results.

Let a unit cube be extended to a length $1 + e$ by a load L, and let the reduced area of the cross-section be A. Then the tension per unit area or the stress P is given by—

$$L = AP,$$

and if stress is proportional to strain,

$$P = Me, \text{ or } L = AMe,$$

where M is the constant, called Young's modulus and sometimes (though improperly) *the* modulus of elasticity. As was shown above, exactly one-third of the load is employed in producing dilation, however great L may be. Hence if k is the modulus of compressibility, the volume of the distorted cube is $1 + L/3\,k$. The volume is also the area of the distorted mass multiplied by its length, or $A\,(1 + e)$. Thus—

$$A = \frac{1 + L/3\,k}{1 + e}.$$

Substituting this value in the last equation gives an equation between load and strain, viz:

$$L - Me + Le\,\frac{3\,k - M}{3\,k} = 0,$$

*Quoted by P. G. Tait, "Properties of Matter," 1890, p. 204, from Hooke's lectures "de Potentia Restitutiva."

which is an hyperbola in L and e asymptotic to—

$$e = \frac{-3k}{3k - M}, \text{ and } L = \frac{3kM}{3k - M}.$$

Thus the fundamental assumption really made in the theory of elasticity is that the load-strain curve is an hyperbola instead of the straight line which Hooke supposed to represent the relation. The difference, however, as already remarked, is without consequence, so long as deductions from it are confined to very minute deformations.*

Stress System.—Any force acting on one face of a cube may be resolved into a normal component and two tangential components acting in the directions of the edges of the face. Hence the most general system of forces of constant direction acting on a cube is resoluble into six normal components and twelve tangential ones. If the center of inertia of the cube is at rest, the normal forces on opposite faces must be equal, and

---

* *Nature of the Proof of Hooke's Law.*—Hooke's law holds good, or, in other words, there is a linear relation involving a finite parameter between small stresses and strains, provided the stress-strain curve fulfills two conditions, viz., that the curve is continuous both in form and value, and that the tangent of the angle which it makes with the axes at the origin is finite. It seems to me that some discussion and even some confusion would have been avoided if elasticians had taken this geometrical view of the functions rather than a purely algebraical one. Thus Green simply assumed that the stress-strain function was developable, and that the development contained a term in which only the first power of the variable appeared, while Clebsch seems to have looked upon this algebraical relation as a mathematical necessity. This it certainly is not, for there are many continuous functions the development of which contains no term in the first power of the variable. These all represent curves which coincide with one of the axes at the origin; *e. g.*, the hyperbola referred to the vertex as origin.—Mr J. W. Ibbetson, in his excellent Mathematical Theory of Elasticity, makes an attempt to demonstrate Hooke's law by pure reason, independently of experiment. He expressly assumes, however, that the curve is continuous, and he states, without any attempt at proof, that the rate of variation of any traction component with any strain coördinate can never change sign or vanish. This last is equivalent to asserting that the curve cannot coincide with either axis at the origin. These two assumptions together cover the whole ground of Hooke's law, and really leave nothing to be proved.—Saint-Venant, in his edition of Clebsch, p. 40, attempted to show that if the internal stresses of an elastic mass depend in any continuous manner on the mutual distances of the molecules, Hooke's law follows. He points out that continuity involves a linear relation between the differentials of a function and the *corresponding* differentials of any variable. He then shows that on the assumption made corresponding small stresses and strains are corresponding differentials, and deduces the conclusion stated above. This argument does not satisfy me at all, for though one may undoubtedly write $df(x) = A\,dx$, where A is constant and the relation is therefore linear, yet A may have and often does have the values zero or infinity. Saint-Venant made no attempt in the passage referred to to show that A must be finite in the case of elastic strains, and seems to have overlooked the necessity for such a proof.

In the same work, page 39, this great elastician forcibly remarks: "Generally and philosophically no purely mathematical consideration can reveal the manner in which the forces acting on the elements of a body and the geometrical changes which they produce depend upon one another." Experiment alone, and only somewhat refined experiment, betrays the fact that even the hardest substances yield somewhat to the smallest pressures, and that the stress-strain curve is continuous in form as well as value from positive to negative strains. One set of experiments is needful to show that a fly lighting on the end of a steel bar which is clamped at the center distorts it, and another set is required to show that the distortion is of the same absolute amount whether the fly settles on the upper or the lower end of the mass.

the twelve tangential forces must consist of six couples, each tending to produce rotation.

In this paper consideration is confined to those cases in which there is a tendency to rotation only about the line $o\,z$, and this limitation eliminates four of the couples. Thus the case to be considered here consists of three pairs of normal forces and two unequal couples tending to produce rotation in opposite directions. This force system is shown in the following diagram:

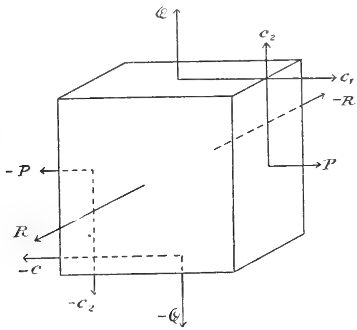

FIGURE 4.—*System of Forces.*

It has already been shown that any normal force, whether finite or infinitesimal, is resoluble into a dilation and two shears, exactly one-third of the force producing dilation, and the remainder producing two equal shears at right angles to one another. Analyzing each of the normal forces P, Q, R separately, it will appear that the action of all of them may be tabulated as two shearing stresses and a dilation—thus:

Axes of	x	y	z
Dilation..........	$\frac{1}{3}(P+Q+R)$	$\frac{1}{3}(P+Q+R)$	$\frac{1}{3}(P+Q+R)$
Shear............	$-\frac{1}{3}(Q+R-2P)$	$\frac{1}{3}(Q+R-2P)$	0
Shear............	0	$\frac{1}{3}(Q+P-2R)$	$-\frac{1}{3}(Q+P-2R)$
Sum............	P	Q	R

Turning now to the couples C_1 and C_2, and supposing $C_1 > C_2$, their combination is equivalent to two equal and opposite couples, each equal

to C_2, and a single unbalanced couple, $C_1 - C_2$. The combination of two equal and opposed couples is easily shown to be equivalent to a shear, the axes of which bisect the angles made by the component forces.* Here, therefore, the balanced couples are equal to a shear at 45° to P or Q.

There now remains a single unbalanced couple tending to produce rotation of the mass about oz. Unless still other external forces are introduced, this couple will merely rotate the mass without strain. If, however, one of the faces of the cube is compelled to coincide with a fixed plane having the same direction as the forces of the couple, as if the mass rested on or against an inflexible frictionless support, this couple, together with the resistance, will effect distortion and will convert the square section on the xy plane into a rhomb with two of its sides parallel to the fixed plane. The distortion thus produced will consist merely in a tangential shifting of planes parallel to the support and will involve no change of volume. In short, the strain is shearing motion or scission.

No system of forces of constant direction and constant intensity will produce scission. The combination of a couple and an inflexible resistance is equivalent to a stress system like that of a simple shear, but which undergoes rotation relatively to the fixed axes of reference during strain. The dynamic origin of a scission thus differs essentially from that of a shear.

If a cube resting upon an inflexible support coinciding in direction with ox were subjected to the force system of figure 4, the couple C_2 would be inoperative and the stress system would reduce to dilation, axial shears, and the rotational shearing stress which produces scission. This last may be called scissive stress.

No support is absolutely inflexible, and in real cases of supported masses the strains produced will be of a character intermediate between those produced when there is no support and when the support is ideally rigid. Such strains evidently involve both scission and a shear at 45° to the axes.

On the whole, then, the entire force system, including a resistance to rotation, produces a dilation, a shear in the yz plane, two shears in the xy plane, one of them at 45° to the axes, and a shearing motion in the xy plane. The most general strain discussed in preceding pages corresponds to any combination of these strains, each of which has been treated in detail. It has also been shown that a general strain of the type here treated is resoluble into just these components.

*See an elementary proof of this proposition in Bull. Geol. Soc. Am., vol. 2, 1891, p. 55.

LINES OF UNALTERED DIRECTION.

It was shown above that, in general, three diameters of the strain ellipsoid have the same direction after strain as before strain.* It is usual to assume that these same lines retain their direction during the process of strain,† but this appears to be true only under certain limitations.

If the displacements a and b are connected by the equation $a = mb$; formula (7), which assigns the position of the lines of unchanged direction in the $x\,y$ plane, becomes:

$$tan\ \varkappa = \frac{f - e}{2\,b} \pm \sqrt{m + \left(\frac{f - e}{2\,b}\right)^2},$$

and the position of the axes of the principal ellipse at the inception of strain is given by—

$$tan\ 2\,\nu_0 = \frac{(m + 1)\,b}{e - f}.$$

Hence one may write—

$$tan\ \varkappa = -\frac{m + 1}{2}\left\{cot\ 2\,\nu_0 \pm \sqrt{\frac{4\,m}{(m + 1)^2} + cot^2\ 2\,\nu_0}\right\}.$$

In this formula ν_0 depends solely upon the direction of the external force relatively to the resistance and not upon its intensity. Consequently, if the $tan\ \varkappa$ is to preserve its initial values throughout the straining process, m must be constant. Now, the displacements may be such that a or b is zero throughout deformation, and m is then constantly zero or infinity. It may also happen that $a = b$, so that $m = 1$, and this case also involves no hypothesis as to a relation between stress and strain in homogeneous matter; but if m is a finite quantity differing from unity, the assumption that m is constant is equivalent to the hypothesis that the ratio of the displacements bears a constant relation to the ratio of the stress components which produce them. This hypothesis is only justifiable when the strain is very small.

When there is no rotation, or when $a = b$, the elastic cube acts as if it rested upon an inflexible support and were affected by stresses axially disposed. When one of the displacements a or b disappears, the strain involves only axial deformations and scission. This again implies the presence of an inflexible support or an equivalent rotating system of forces. Hence the lines which have the same direction after strain as

* Two of these diameters may coincide and both of these may become imaginary.

† Thomson and Tait speak of these lines as unaltered in direction *during* the change of strain, but they may have meant *by* rather than during. Nat. Phil., section 181.

before strain will keep this direction during strain only when the mass acts as if it rested on or against an inflexible support.

If this support is parallel to $o\,x$, either $tan\ \varkappa = 0$ or:

$$tan\ \varkappa = \frac{f - e}{b} = tan\,(90^\circ + 2\,\nu_0).$$

Properties of Matter.

Viscosity.—The ideal elastic substance is one which requires a perfectly difinite stress to hold it permanently in any given state of strain at a given temperature. This stress is wholly independent of previous states of strain or rates of straining. Real substances fulfill this definition only under certain conditions, and careful experiments always show that the more rapidly deformation is produced, the greater is the resistance to be overcome. Thus a spring, suddenly stretched by a given weight, yields rapidly to a certain extent and may seem to become stationary; but careful observation shows that is continues to yield slowly to the traction for a time, though it ultimately comes to rest. If the material were ideally elastic, it would immediately assume this ultimate state of strain, and the fact that the attainment of equilibrium is gradual proves that the original resistance is a function of the rate of deformation. Fluids show similar phenomena.

Viscosity is that property in virtue of which matter presents to stress a resistance into which the rate of deformation enters as a factor. Viscosity and shear are inseparable, and mere dilation is unattended by viscous phenomena.* The coëfficient of viscosity of a substance is *ceteris paribus*, the shearing stress required to produce the unit shear in the unit time. The degree of viscosity is considered as increasing with this coëfficient, so that sealing wax and tar are more viscous than water, and steel is more viscous than lead or copper.

Substances which yield indefinitely though slowly to stresses, however small, are now known as viscous fluids. Those which in the course of time reach statical equilibrium under the action of deforming stress, such as tallow and steel, are called viscous solids.

If stress is applied very slowly (or rather infinitely slowly) viscosity does not come into play. Thus, a viscous solid or fluid in permanent

* Viscous resistance is often likened to friction. Each is a dissipative resistance to tangential motion, but there are marked differences between them. Friction exists only where there is normal pressure, and is therefore wholly absent on the planes of maximum tangential strain in a shear. Friction also has its maximum value when the surfaces between which it exists are at rest. Viscous resistance opposes relative motion of surfaces between which there is no normal pressure when the rate of motion is finite, but vanishes when this rate is infinitesimal. Thus there is rather an analogy than a similarity between viscosity and friction.

statical equilibrium acts like an ideally elastic or ideally fluid mass. Under these conditions the resistance which a solid offers to deformation is due entirely to its "rigidity," this term being defined in the theory of elasticity as the degree of resistance which a solid in permanent equilibrium opposes to stresses tending to change its shape.* Under this definition india-rubber and tallow possess rigidity as well as cast iron, but the modulus of rigidity of the metal is greater than that of the gum or the fat. In short, rigidity is an essential property of solids.

A highly viscous fluid subjected to a stress of brief duration presents great resistance to deformation. Thus, if the earth were substantially a mass of sufficiently ultra-viscous fluids, it would behave to the attractions of the sun and moon sensibly like an infinitely rigid body, because of the rapid change in the direction of these attractions. There are valid grounds, however, for the belief that the earth is really solid.

The viscosity of rocks often controls the directions in which they yield to stress. When two equal stresses acting on the same rock-mass change their directions at different rates, that stress which rotates at the smaller rate will encounter the smaller resistance and will produce the greater effect. It has been shown in the earlier part of this paper that all rotational strains are accompanied by relative tangential motion on two sets of mathematical planes which rotate relatively to the mass at different rates. The difference of their effects due to viscosity will be discussed under the head of geological applications.

Flow.—At least some solids in the so-called "state of ease" (freedom from internal partial constraint) almost completely recover their original form after small strains when time is allowed to overcome the viscosity. It is apparently true of all bodies, however, that when strained beyond a certain limit short of rupture, they are permanently deformed. The process by which this deformation is effected is termed flow, and the limit at which a substance initially in a state of ease begins to flow is called the limit of solidity. When the limit of solidity differs but little from the ultimate strength, the substance is known as brittle. When the limit of solidity is a fixed quantity, so that any excess of stress produces continuous flow, the mass is said to be plastic. When a continuously increasing stress is needful to produce continuous flow, the substance is said to be ductile, and in this case a "hardening" of the mass attends the flow, as, for example, in the manufacture of wire.

Plastic flow thus differs from ductile flow. I am not aware of any phenomena which point decisively to the existence of ductility and the attendant hardening among rock masses, but it cannot be amiss to call

* The word rigidity, as used in the theory of elasticity, has nearly the same meaning as stiffness in common parlance.

attention to this property, which possibly plays some part in the interior of the earth if not near the surface.

Plastic flow certainly plays an important part in geological mechanics. The motion of glaciers is known to be in part ascribable to it, and it is clearly evinced in the details of rock structure. At great depths below the surface a partial gradual relief of strain in any rock mass will bring to bear a gradual increase of stress difference, which may be considered entirely indefinite in amount. Granting, then, that there is no infinitely brittle rock or no rock in which the ultimate strength falls short of the limit of solidity, flow must ensue at great depths whenever a sufficient relief of strain occurs. No geologist needs to be reminded of the instances pointing to such flow. They are innumerable and most various.

If a mass capable of plastic flow is suddenly subjected to a definite load greater than it can bear without flowing, one-third of the load will immediately be employed in compression and the process of flow will produce no further modification of the volume. Flow is thus continuous shear.

The shearing process must take place along certain lines, and these must be the lines which are first strained beyond the limit of solidity. In other words, flow must take place along the lines of maximum tangential strain discussed in a former part of this paper, and which by (10) stand at an angle $90° - \omega$ to the line of a simple, direct pressure. When the load is of fixed amount, the stress will gradually diminish as the mass flattens out; so that the last lines of flow will make a smaller angle with the line of force than the earlier ones. A greater amount of flow would occur along the earliest lines affected. If the mass were of such a character as to show evidences of the relative motion after equilibrium had been reached, a cross-section of it would reveal a structure at least comparable with schistosity, the flatter lines being more pronounced than the steeper ones.

Relation of plastic Solids to Fluids.—Let S be the resistance which a plastic solid opposes to distorting stress at the elastic limit, and let n be the stress which would be required to produce the unit shear if the mass were perfectly elastic (or, in other words, the modulus of rigidity); then if stress is proportional to strain, S/n is the shearing strain which the mass experiences at the elastic limit, and any greater strain would be accompanied by flow. If the mass continues to flow as long as the stress is maintained above the fixed limit S/n, the substance is known as perfectly plastic.

If S is infinitesimal, the mass will yield to any shearing stress, however small. Such a mass, resting on a level surface, would spread out to a layer of infinitesimal thickness, much like a fluid. It does not follow,

however, that because S is very small, n is also small. The rigidity of a mass seems quite independent of its elastic limit. Thus wrought iron and cast steel have nearly the same modulus of rigidity, though the elastic limit is very different for the two substances. A material, then, may have a very low elastic limit and yet oppose great resistance to deformation within that limit.

If the rigidity of a mass is great, the lines of maximum tangential strain under pressure will make angles of little more than 45° with the line of pressure. If such a mass is prevented from undergoing relative motion in these directions, a much greater force will be necessary to compel it to move in any other direction. Fancy a cube of matter of low elastic limit, but great rigidity, placed in a shallow tray just wide enough to receive it; and let a small, uniformly distributed pressure be applied to the upper surface of the cube. Then, above the edge of the tray, the mass would break down at angles of about 45°, but the laminæ standing

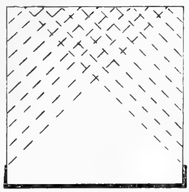

Figure 5.—*Plastic Solid under Pressure.*

at 45° and supported by the tray could not move sensibly. The result would be that a pyramidal mass would remain in the tray, forming an angle of 45° with the line of pressure.

This is substantially the way in which a body of solid, discrete particles would act. A cube of such material released in a tray would resolve itself into a pyramid, sloping at the angle of rest. It is also easy to show that the maximum value of this angle is 45°.* A mass of very fine powder composed of frictionless spheres would be perfectly plastic, inasmuch as it would yield to any shearing stress, however slight, which were not resisted by external constraint. The elastic limit would also be zero. Its rigidity could be displayed only when flow were prevented by constraint in the direction in which flow tends to take place. It would then evince rigidity by its ability to retain a pyramidal shape. In short, a mass resembling shot of infinite fineness appears to represent the case of a perfectly plastic solid with infinitesimal elastic limit.

* The angle of rest is, say, ρ, and $\tan \rho = R \div N$, where N is the normal pressure, and R the frictional resistance due to this pressure. This resistance cannot exceed the pressure to which it is due, and $R \div N$ cannot exceed 1, the tangent of 45°.

Consider now the case in which n is very small and S great. This case also bears some resemblance to a fluid. A cube of material with these qualities would yield to the slightest pressure, and the strain ellipsoids would be flattened to infinitely thin disks. The lines of maximum tangential strain would therefore be perpendicular to the line of pressure. To convert this solid into a liquid the elastic limit and the rigidity must both disappear; but this is not of itself sufficient. The flow of a liquid takes place perpendicularly to the direction of pressure; consequently, in the solid which approaches infinitely near to the liquid state, the strain ellipsoids must be infinitely flattened before flow begins. This relation is secured if S is infinitesimal and n is an infinitesimal of the second order.

In the discussion of strains it was shown that the lines of maximum tangential strain, or the lines on which flow must take place, make an angle with $o\,x$, which has a certain value, ω. It appears from the above that this angle has a value of 45° for an infinitely rigid solid, even if this solid is perfectly plastic and has no elastic limit, so that it is reduced to molecular powder. For fluids, on the other hand, this angle is zero, and the rigidity is an infinitesimal of the second order. Intermediate values of ω answer to solids of moderate rigidity.

Rupture.—In a homogeneous mass under pressure, rupture must take place on the lines of maximum tangential strain; for rupture is strain carried to such an intensity that cohesion is overcome. A mass in which flow has preceded rupture cannot be regarded as homogeneous, since in the direction in which flow occurs the strength of the mass may be and perhaps must be weakened. In the case of pressure this makes no difference, the tendency to flow and to rupture being in the same direction.

Tensile stresses produce ruptures by a different method. One can conceive of a mass breaking up by mere dilation or without any relative tangential motion, while purely compressive forces cannot be imagined as leading to rupture. In tensile strains shears coöperate with dilation. Thus, if a bar under tension is homogeneous, the tension will be relieved by the smallest possible fracture, which is in a direction perpendicular to the axis of the bar. If, however, the bar has undergone flow along the surfaces of maximum tangential strain and has thus been sensibly weakened in these directions, it may split diagonally to the axis or irregularly along some other path of least resistance. Thus, a rubber band when suddenly stretched almost always breaks as straight across as if cut with scissors, but a bar of mild steel gradually stretched to the breaking point often splits diagonally, while a wooden bar gives a most irregular surface of fracture.

In rocks, tensile rupture and fracture by pressure can often be distin-

guished. Granites, and even conglomerates, often break under pressure in extraordinarily smooth, continuous, plane surfaces. Under tension the rupture of granite would follow an irregular surface of least resistance, leaving projecting crystals on each side; and in conglomerates few pebbles would be broken, nearly every one adhering either to one fragment or the other. Stratified rocks under tension would behave much like a wooden bar. Only unusually uniform rocks could give smooth surfaces of rupture under tension. Such surfaces do occur in the case of columnar eruptives, and these columns can be shown to be produced by tension in the cooling mass. Even when tension produces surfaces of rupture which are smooth, they are apt to be curved or broken. In a word, tension tears masses asunder; pressure cuts them to pieces.

Geological Applications.

Cases to be considered.—It is probable that pure dilation and pure irrotational shear are strains of rare occurrence in rock masses. One of these requires two, the other three pairs of forces acting at right angles to one another with identical intensity. Simple pressure, on the other hand, is common, especially where disturbances are not in progress. During orogenic changes inclined pressures must be frequent. The most important stress systems are therefore direct pressures and inclined pressures. The last includes two cases, in one of which the mass suffering pressure rests upon or against an unyielding support, while in the other the mass rests upon or against materials which yield readily. In the former of these cases the stress system reduces to a simple pressure, compounded with a scissive stress; in the latter to a pressure and a shearing stress.

In dealing with each strain viscosity and a tendency to flow or rupture must be considered, the aim being to relate actual phenomena to their immediate causes and to enable the geologist, in some measure at least, to judge of the local direction of the forces the effects of which he observes.

When gravity acts upon a mass homogeneous strain is, strictly speaking, impossible, excepting within infinitesimal limits of space, each level surface being subjected to greater pressure than the next above it. On the other hand, the forces involved in the deformation and fracture of rocks are very great, except in some extreme instances, such as that of moist clay. For ordinary firm rocks the ultimate strength is such that a column of from one to several thousand feet in height would be needful to produce at its base a pressure sufficient to induce rupture. Consequently, in masses of such material from a few score of feet to a few hundred feet in thickness, gravity plays but a small part compared with

rupturing stress; and portions of the rock having dimensions of this order may often properly be regarded as homogeneously stressed. When large masses are similarly strained, gravity may determine in which of several directions, all equally stressed by external pressure, rupture will take place. Cases of such determination I have discussed in a former paper.*

Effects of direct Pressure.—A direct, uniformly distributed pressure of sufficient intensity, applied to an elastic brittle mass presenting great resistance to deformation, would induce fracture. The ruptures would take place along those lines subject to the greatest tangential strain, since these are the directions in which the material would first be strained beyond endurance. These lines would stand at 45° to the line of force if the mass presented infinite resistance to deformation. If this resistance is not infinite, they will stand at greater angles to the line of force. The angle which the normal to the direction of rupture makes with the line of force is called ω in the discussion of the strains (see p. 34).

There will generally be more than one direction of rupture, and in masses the thickness of which in the direction of pressure is considerably smaller than the lateral extension, there will often be four systems of parallel fissures, two systems answering to each of the two equal shears arising from simple pressure. If, however, there is any inequality of resistance in the plane perpendicular to the line of pressure, whether this is due to the character of the mass under pressure or to inequalities in the support which this mass receives from its surroundings, the strain ellipsoid will have three unequal axes, and rupture will take place only in the plane of the greatest and the least of these axes. In this very common case the mass will be divided into columns, with angles depending upon the strain. When the mass is large and the pressure is horizontal, gravity opposes the tendency of the vertical axis of the strain ellipsoid to elongate, and rupture will tend to take place by relative motion in horizontal planes, separating the rock into vertical columns. The constraint of surrounding masses may outweigh this tendency.

Something can be said of the spacing of the fissures thus formed, but this subject can be most conveniently discussed under the head of inclined pressure.

If the pressure continues after rupture has occurred, the blocks or columns will grind against one another producing slickensides, and sometimes further ruptures, of which the discussion will also be deferred.

Many rocks under the action of direct pressures rapidly applied behave approximately as highly elastic brittie masses of great rigidity, and in these cases the range of the planes of maximum strain is practically *nil*. Consequently, systems of fissures at sensibly right angles to one another

* Bull. Geol. Soc. Am., vol. 2, 1891, p. 62.

are not infrequent, nor is it very unusual to find such a pair of systems of fissures accompanied by a second similar pair in a plane at right angles to the first. The residual blocks are then bounded by from four to eight planes. In the last case four of the planes are parallel to the other four.*

In many cases the rock does not rupture without previous deformation of considerable amount. When this happens the lines of rupture make an angle of more than 45° with the line of force. The normal to the direction of rupture then makes an angle ω with the line of force, and this angle decreases with the deformation. If the deformation were very great, as it would be with a mass of india-rubber, ω would approach zero. If the direct pressure were relieved by rupture and the rock were perfectly elastic, the residual fragments would recover their original shape, and their acute angles would then lie in the line of force.

Thus when rocks show fissures cutting one another at acute angles it is certain that finite deformation has taken place. If the mass has remained under tension, the line of force when direct bisects the obtuse angles. If the mass has been relieved of pressure and the rocks have acted as elastic masses, the line of force bisects the acute angles.

It is usually possible from general conditions to judge which of two rectangular directions is the more probably that from which a rupturing force has acted. I have, however, never yet met an instance in which it seemed to me that the line of force bisected the acute angles of fissure systems. Orogenic forces are commonly very persistent, and even if a mass behaved as substantially elastic up to the moment of rupture, it is improbable that the residual blocks would continue capable of regaining their original shape after the lapse of, say, even a few years. In many cases it is quite clear that deformation has become permanent. Thus I have examined very numerous pebbles in conglomerates, some of which had been much flattened by pressure and others also much fractured. The direction of flattening was then a certain indication of the direction of force, and this direction bisected the obtuse angles between the fissure systems intersecting the pebbles. In other cases the character of slickensides and accompanying faults shows that no reversal of motion has taken place, and that the residual masses must have lost the elasticity which they seem to have exhibited up to the moment of rupture.

Observations on artificial structures seem to confirm this opinion. It has been pointed out by Mr. Clarence King and others that slabs of marble supported at their ends or corners gradually sag toward the center. So, too, in old buildings, such as the Alhambra, I have seen slabs of rock very much bent by end pressures acting for hundreds of

* When a rock fragment is bounded by planes with more than four differently directed normals, it must have undergone successive ruptures.

years. This does not imply that there is no true elastic limit, but only that it is lower than brief laboratory experiments would lead one to suppose. Were there no elastic limit, it seems to me that we should find, for example, quartz crystals in vugs among the more ancient rocks sensibly distorted by their own weight.

Usually then the line of a simple, direct pressure which has produced two or four systems of fractures in large rock masses, or in the pebbles of conglomerates, will be found to bisect the obtuse angles between the fissures as the mass now stands. In any case, where it is suspected that the line of force bisects the acute angles between fissures, the slickensides should be minutely examined to ascertain whether they show reversal of motion, and all the attendant phenomena should be investigated.

When a simple pressure on a rock mass increases very gradually, it will for some period exceed the elastic limit of the rock and fall short of the ultimate strength. Flow must then take place. The only feature of this flow which will reveal itself to observation will be the relative movements of adjoining particles. Hence, although the path in space of each particle will be hyperbolic,* the evidence of movement will indicate relative transfer of adjoining particles in opposite directions along lines of maximum tangential strain. The energy of this relative movement will evidently increase with the excess of the pressure above the limit at which flow begins, sometimes called the limit of solidity.

Thus, if one supposes the pressure suddenly to surpass the limit of solidity and then to be kept constant, the mechanical effects of the relative motion (and the chemical effects attending the expenditure of energy) will be very pronounced on the lines on which flow begins. As the process continues and the stress diminishes with the increase of the area of the mass, the lines first affected will make an increasing angle with the line of force, while the new fibers of the material which are forced into the direction of maximum strain will be less and less affected.

The result will at least resemble schistose structure and will be marked by the presence of lines of relative movement intersecting one another at very acute angles. In the case of direct uniform pressure there will be four such sets, each set at a large angle to all the others.

If the load were to increase in the same proportion as the area of the loaded mass, so that the stress would be kept uniform, an indefinite amount of flow might be produced, provided that the rock is not hardened

* During flow there is no progressive change of volume. Hence, a point for which at the inception of flow $x = 1, y = 1$, will be moved to a point x', y', and $x'^2 y' = 1$. The curves of this form are sometimes called the lines of flow They would be more aptly called lines of *absolute* movement. They should carefully be discriminated from the lines of *relative* movement, which are straight. The latter are the only ones of which the deformed mass can give direct evidence. In the case of simple shear the lines of absolute movement are simple hyperbolas asymptotic to the axes.

like drawn wire. If the flow were very great (literally infinite) the lines along which relative movement took place at the inception of strain would become horizontal. The schistose partings would then in each set range through the angle ω.

Relative motion, in a mass subjected to direct uniformly distributed pressure, can only take place perpendicularly to the line of pressure when the strain ellipsoids are infinitely thin discs or when the rigidity is zero. In other words, only liquids, viscous or otherwise, can act in this manner. The behavior of semi-fluid material, like wet clay, approximates closely to that of a viscous fluid.

Rigid Disc in resisting Medium.—The behavior of an elastic mass under simple pressure leads to an extremely simple method of proving a dynamical proposition of much importance to geologists. A simple pressure acting against a resistance converts any sphere of unstrained matter into an oblate ellipsoid of revolution, the minor axis of which is in the direction of the pressure. If the constant pressure were to exceed the constant resistance, the mass would move in the direction of the pressure and of the minor axis of the oblate ellipsoid. Now, it is a well-known fact that the whole or any portion of an elastic mass which is in equilibrium, whether at rest or in motion, may be supposed to become infinitely rigid without disturbing the equilibrium. This is an almost self-evident proposition, for a mass is in equilibrium only when there is no influence tending to change its form, and it therefore makes no difference whether this form is capable of change or not. Hence in the present case the strain ellipsoid may be supposed replaced by a rigid mass. Consequently a rigid ellipsoid of revolution moving under the influence of a pressure against a resistance will be in equilibrium when it opposes its greatest surface to the resistance.

Similarly an elastic sphere under tension becomes a prolate ellipsoid, and consequently a rigid prolate ellipsoid moving under the influence of tension against resistance will be in equilibrium when its longest axis coincides in direction with the tension.

If a cube were circumscribed about either of these spheres, with four of its edges in the direction of the force, it would become a rectangular parallelopiped with sides parallel to the axes of the ellipsoid. Any plate or rod may be made up of a single layer or row of such flattened or elongated cubes. Hence any rigid disc or rod moving against a resistance under the influence of pressure will be in equilibrium when its smallest dimension is in the direction of pressure. If it moves under the influence of traction, its longest axis will fall into the line of traction.

If a flattened pebble is dropped into a running stream, the water will exert a pressure upon the stone until its inertia is overcome, and during

this time the pebble will tend to swing across the current so as to present its greatest area to the pressure. As soon as the resistance due to its inertia is overcome, the pebble will sink through the water as if the fluid were at rest till its edge touches the bottom, and it will then tip down stream till it meets support. In rapid steams irregularities in the bottom cause local upward currents, which project pebbles into the main current much as if they had been dropped into it. These pebbles sink to the bottom again where the movement of the water is more uniform. Many pebbles thus deposited will, with few exceptions, be inclined down stream and will rest against one another, like overlapping tiles.

This relation explains the fact that both in modern streams and in the ancient river channels containing the auriferous gravels, many of which have been tilted since their deposition, the pebbles, as miners say, "shingle up stream," or, as zoologists would express it, "imbricate" toward the source. Elongated, rod-like pebbles are usually found lying across the channel. The indication afforded by this behavior of pebbles seems entirely trustworthy so far as the local current is concerned. In applying it, however, it must be remembered that powerful streams are often accompanied near shore or close to obstructions by local "back currents," in which the pebbles would be arranged in a direction opposite to that of the main stream.

If a flat pebble or a mica scale is allowed to subside in relatively quiet water, the fluid may be considered as exerting a pressure on the lower side against a resistance due to the action of gravity on the stone. The disc will then tend to assume a horizontal position. It is for this reason that allothigenetic mica scales in sandstones or other rocks usually follow the direction of the bedding. In massive sandstones this is an assistance in determining the true stratification.

A very familiar illustration of the action of the strain ellipsoid moving against resistance is afforded by a bubble of gas rising through still water. The spherical bubble is compressed to an ellipsoid, which might be replaced by a rigid mass of the same density, and it rises with its equator in an almost perfectly horizontal plane.

On beaches pebbles are sometimes imbricated for a few feet in one or another direction and sometimes lie nearly flat. The constant reversal of the currents due to breaking and retreating waves prevents any extensive methodical arrangement, and this fact is of assistance in discriminating marine gravels from river deposits.

There are also instances of the almost self-evident fact that a rod-like mass moving under the influence of traction, like a vessel under tow, will move end on. In glassy rocks, such as many rhyolites and andesites, the mass often shows a banded structure, marked by the presence of

microlites, most of which are parallel to the banding. These microlites are no doubt of greater density than the glass, but, on account of the viscosity of the melted glass and the enormous surface per unit volume which the microscopic prisms expose, they cannot be supposed to attain their actual arrangement as a result of gravity like the mica scales in sandstone. On the other hand, if one supposes an irregular orientation of the microlites in the glass, and that tangential motion has been set up between adjacent layers of the viscous mass, every microlite standing across the direction of relative motion would be swung into the line of relative motion by the opposite traction exerted on its two ends by the moving layers. It appears to me, therefore, that "rhyolitic structure" indicates "shearing motion" or, as I have called it, *scission* in the direction of the banding.*

Inclined Pressure and yielding Medium.—An inclined pressure acting on a tabular mass of rock is equivalent to a direct pressure and a tangential force. This last, with the resistance necessary to keep the center of inertia of the rock at rest, forms a couple. If the rock is surrounded by masses of comparatively feeble resistance, it will then rotate until the couple is exactly balanced by the resistance to rotation. The rock is thus subjected to the action of a simple pressure and two balanced couples, constituting a simple shear, neither of the axes of which coincides with the line of pressure.

As has been shown above, the strain produced by a pressure and a shearing stress is a rotational one, the amount of rotation, however, being small as compared with that involved in some other strains. One of the directions of maximum tangential strain will therefore sweep over a greater range of material particles than the other, or will affect a given set of particles for a shorter time. That set of planes of maximum strain which shifts its position more rapidly will encounter greater resistance from viscosity and will produce the smaller effect.

If the mass is strained beyond the elastic limit, but not to the point of rupture, a schistose structure will result, but one set of schistose partings will be confined to a somewhat smaller angle than the other and the more pronounced partings will be associated with the smaller angle.

If the pressure is intense enough to produce rupture, fracture will take place chiefly along the partings which have the smaller range.

The axes of the strain ellipsoid will bisect the angles which the last schistose partings make with one another, and the minor axis of the

* The above discussion is incomplete. A full treatment would of course assign a definite value to the couple which resists the tilting of a disc moving in a fluid. The reader will find the subject more fully developed in Thomson and Tait, Nat. Phil., sections 320-325, with interesting instances. That discussion is decidedly difficult, while the main points in which geologists are interested seem to be adequately demonstrated by the exceedingly elementary method here presented.

strain ellipsoid, or the direction of maximum compression, will lie between the line of pressure and the compressive axis of the additional shear.

When the rock is ruptured without sensible deformation the strain under discussion will not be rotational and will be indistinguishable from that which would result from a simple shear; for in the $x\,y$ plane one of the shears arising from direct pressure coöperates with the shear resulting from the preliminary rotation, and their combined effect will be greater than that of the second shear in the $y\,z$ plane arising from the direct pressure component.

The character of the finite strain is best seen by an illustration such as that in the diagram, figure 6, *A*.

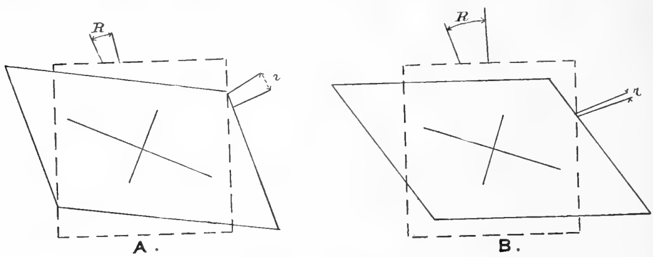

FIGURE 6.—*Strained Cubes.*

The dotted squares are strained to the rhombs, drawn with full lines. *A* results from two shears at 45° to one another, the ratio of each shear being 5 / 4. *B* results from a shear and a scission, the ratio of each of the two shears involved being also 5 / 4. The central crosses mark the direction of the ellipse axes. The angle R is the material angle through which one set of planes of maximum tangential strain sweeps, and r is the other corresponding angle. In *A*, $R - r = \nu - \mu = 2^{\circ}\,45'$. In *B*, $R - r = 15^{\circ}\,21'$.

Inclined Pressure and unyielding Resistance.—When a tabular mass of rock subjected to inclined pressure rests against a mass which does not yield considerably, the free couple which results from the tangential component of the pressure and the resistance of the supporting mass can only be equilibrated by strain in the rock itself. The strain will therefore include as one component a shearing motion or scission.

This strain is rotational, the angle of rotation being far greater in this case than in that of a yielding support. The rotation is here of the same order as the strain. Consequently one set of planes of maximum tangential strain will sweep through the mass much more rapidly than the other, and the difference in their action will be very pronounced. The nature of the distortion is seen in figure 6, *B*.

Partial Theory of the Spacing of Fissures.—When a slab of rock resting broadside against an inflexible support ruptures under the influence of a pressure inclined to the supporting plane, it is easy to see that the pressure can be relieved only by several cracks, which must divide the mass into sheets bounded by planes of maximum tangential strain. Such a division is extremely common on a large scale in granite and other relatively homogeneous masses; on a small scale it is frequent in the pebbles of conglomerates which have been subjected to pressure. It is therefore very desirable to ascertain the conditions which determine the thickness of the sheets.

A slab of rock must evidently rupture in such a manner as to relieve the pressure upon it, and this relief must be accompanied by a readjustment of the fragments. This consideration at once assigns a superior limit to the spacing of the cracks. Suppose, for example, that in a case illustrated by the following diagram cracks were to form only at *a* and *c*, then, since a perpendicular from the upper end of *a* falls between *a* and *c*,

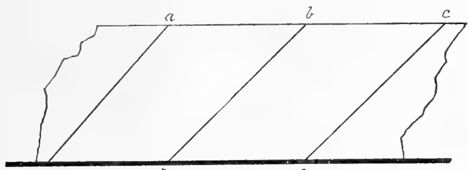

FIGURE 7.—*Widest possible Spacing of Fissures.*

the fragment *a a c c* cannot rotate without increasing its vertical dimension, and the pressure cannot be in any way relieved by the ruptures. But if a third crack, *b b*, is so placed that its lower end is perpendicularly below the upper end of *a*, the fragment *a a b b* can be rotated so as to decrease the vertical dimension, and thus to relieve pressure. Hence the cracks must be at least so near to one another that the terminations of adjacent cracks are in vertical lines, and the higher the angle which the cracks make with the fixed plane, the nearer must they be to one another. This, however, is an extreme case; for an infinitesimal rotation of the vertical line *a b* about any point of it would not diminish the thickness of the mass. The actual distance between fissures must therefore be less than that assigned by this limit.

When the process of straining is so slow that the mass can fully adjust itself at each instant to the external forces (an important limitation) it seems impossible to avoid the conclusion that the actual spacing will be such as to depotentialize the greatest possible amount of energy for a given length of fissure. In other words, the cracks will be so disposed as

to "do the most good." If so, the spacing can be determined if one can succeed in expressing in exact terms the depotentialization of energy per unit length of crack.

The lines of maximum tangential strain make angles ω with the major axis of the strain ellipse. When the strain is due to a pressure at a positive, acute angle φ with the fixed plane (parallel to $o\,x$), the major axis makes an acute negative angle ν with $o\,x$. That set of planes of maximum tangential strain which have the smaller range during the process of strain, and upon which there is the least viscous resistance, then makes an angle $\omega + \nu$ with $o\,x$.

Let w be the thickness of one of the sheets into which rupture may divide the slab of rock, and let ϑ be the angle which the diagonal between the obtuse angles of the sheet makes with $o\,x$, as indicated in the following diagram, figure 8. Then, if the thickness of the slab at the moment of rupture is $2\,l$, a little consideration shows that—

$$w = 2\,l \cos(\nu + \omega) \left\{ 1 - \tan(\nu + \omega) \cot \vartheta \right\}.$$

It is evident that the total length of the cracks is inversely proportional to the thickness of one sheet or to w.

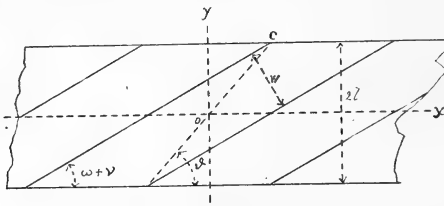

FIGURE 8.—*Spacing of Fissures.*

To determine the relief of pressure it is convenient to begin by considering a mere change of strain. Suppose a slab to be in equilibrium under the action of a simple, direct pressure. Let the mass now undergo a small change in physical properties, such that it yields by a small additional amount to the pressure. Then the potential energy of the system is diminished in proportion to the amount of this secondary yielding, measured in the direction of the force. Only one fiber passing through the center of the mass, however, will move solely in the same direction in which the pressure acts, all other particles moving on hyperbolic lines.

If the pressure were inclined to the surface at an angle φ, the depotentialization of energy under similar circumstances would also be measured

by the movement of particles in the direction of the pressure, irrespective of the movements which they execute in other directions.

The rupturing of the slab into sheets may be regarded as a change in its physical properties such as is contemplated above.

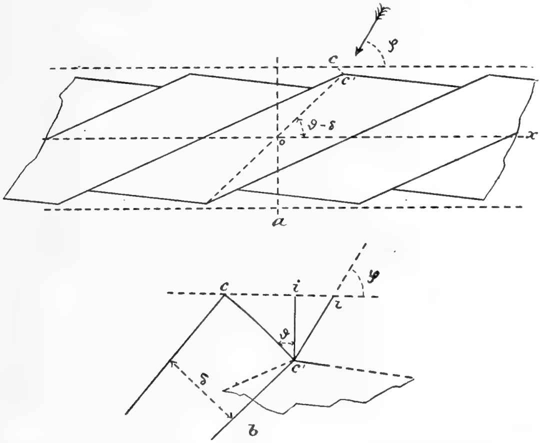

FIGURE 9.

Cut *a* shows the same mass as figure 8, the sheets now being rotated through a small angle δ by the pressure acting in the direction ϕ. Cut *b* represents the corner c' of one sheet on an enlarged scale, together with the original position of this corner at c.

The line $c'\,r$ is the distance measured in the direction of the force through which the point c has moved in passing from c to c', so that $c'\,r$ is proportional to the depotentialization of energy. The angle of rotation being small and arbitrary, say, δ, the angle $cc'\,i = \vartheta$ and—

$$(c'\,r) = (cc')\,\frac{\cos\vartheta}{\sin\varphi}.$$

Then, too, $(cc') = (oc)\,\delta = l\,\delta\,/\sin\vartheta$, so that the relief of pressure varies with the line—

$$(c'\,r) = \frac{l\,\delta}{\sin\varphi}\cot\vartheta.$$

The relief of pressure per unit length of crack therefore varies with—

$$w\,(c'\,r) = \frac{4\,l^2\,\delta}{\sin\varphi}\cos(\nu+\omega)\left\{1 - \frac{\tan(\nu+\omega)}{\tan\vartheta}\right\}\cot\vartheta;$$

and to find the distribution of fissures which will ensure the greatest

depotentialization of energy per unit length of crack, it is only necessary to determine the value of ϑ, which will give the last expression a maximum value. This problem leads at once to—

$$2 \tan (\nu + \omega) = \tan \vartheta,$$

or—

$$w = l \cos (\nu + \omega),$$

a result of very convenient simplicity.

Thus far it has been assumed that only one set of fissures forms in the slab. This case is of frequent occurrence in rocks, but it is not much more frequent than the appearance of two sets of fissures forming large angles to one another. Under conditions such that viscosity does not essentially modify the results, there should be as great a tendency to form fissures on the other set of planes of maximum tangential strain, making an angle $\omega - \nu$ with $o\,x$, as on those planes discussed above.

When two sets of fissures form at large angles to one another they must seemingly develop simultaneously; for, if a single set of sheets were to form first, and secondary fissures were to be produced by the grinding of the sheets against one another, it is easy to see that the secondary fissures would make but a small angle with the primary divisions, and there would be more evidence of movement on the first fissures than on the subsidiary cracks. These cracks would also not in general pass from one primary sheet to the next.

When the two sets of joints form simultaneously, each set must form under similar conditions, and I can think of no reason to suppose that they do not form independently. Hence the theory already developed seems to apply also to the second set of fissures, the only change needful being the substitution of $\omega - \nu$ for $\omega + \nu$.

The results derivable from this theory of division certainly accord with some well known facts. Thus, if a tough mass is acted upon by a shearing tool, it is a matter of daily experience that the mass undergoes a single cut. For this case viscosity comes into play, and by the theory only one set of fissures will be developed, $\varphi = 0$, $\omega + \nu = 0$ and $w = l$, which means that only one fissure will intersect the mass. Again, if one attempts to cut a brittle substance like glass with a shearing engine, the mass, according to experience, shatters instead of simply dividing. By the theory as applied to this case the elastic deformation is extremely small, neither set of planes of maximum tangential strain has a sensible range, and $\omega + \nu = 0$, while $\omega - \nu = 90°$, nearly. Hence only a single fissure will tend to form in the direction $\omega + \nu$, but the mass will be divided into scales of almost infinitesimal thickness in the direction $\omega - \nu$. In other words, the theory substantially accounts for the facts.

In theory as in practice, only masses capable of considerable deformation under the system of external stresses can be divided by a single clean cut.

This conclusion seems to throw some light upon a general feature of geological fractures. In the laboratory rocks are very brittle substances, and every geologist has experienced a feeling of surprise that in natural rock-exposures clean cuts in a single direction are so frequent. It now appears that cuts of this description can occur only when the stresses are such as to produce a considerable elastic or plastic deformation of the mass. There is, of course, abundant other evidence that such stress systems really accompany orogenic movements.

Examples of inclined Pressure.—According to a famous theory developed by Navier and Poisson the ideal isotropic solid is characterized by the property that in a simple elongation of small amount the linear lateral contraction is just one-fourth of the increment of length. Though most elasticians refuse to acknowledge the theoretical basis of this conclusion (viz, that the action between two molecules is reducible to a single force acting between the centers of mass), there is no doubt that several substances, and especially glass, behave sensibly as this theory demands. As some rocks are glasses, it is certainly legitimate to assume, for the purpose of illustrating the theory of rupture developed above, that the relation 1 / 4 holds true.*

Let a pressure F act upon a slab of a rock fulfilling Poisson's ideal at an angle of 30° and let the mass rest against a rigid support. Then if U and Q are the horizontal and vertical components—

$$U = -F\cos 30^\circ = -\frac{F\sqrt{3}}{2};\ Q = -F\sin 30^\circ = -\frac{F}{2}.$$

If also n is the modulus of rigidity, it is easy to show and is well known † that—

$$e = g = -\frac{Q}{10\,n};\ f = \frac{4\,Q}{10\,n} = -4\,e;\ b = \frac{U}{n}.$$

* *Possible Test of Poisson's Hypothesis.*—One of the obstacles attending the discussion of Poisson's solid and the question whether or not the coëfficients of rigidity and compressibility for isotropic solids are independent consists in the fact that it is difficult to determine Young's modulus and the modulus of rigidity for the same body with sufficient accuracy to justify theoretical conclusions. There seems to be a method of direct comparison which would test the question if the experimental difficulties should not prove too great. If M is Young's modulus,

$$f = -F\sin\phi\,/\,M \text{ and } b = -F\cos\phi\,/\,n,$$

or—

$$\frac{b\tan\phi}{f} = \frac{M}{n}.$$

If, then, a testing machine were so adapted as to produce a pressure at 45° to a stationary plane, the deformation of a cube subjected to its action would give $b\,/\,f$ and $M\,/\,n$. If Poisson's hypothesis is verified, $M\,/\,n = 10\,/\,4$.

† Compare Thomson and Tait, Nat. Phil., section 683. For Poisson's solid $3\,k = 5\,n$.

Thus one may express e, f and g in terms of b—

$$e = g = \frac{-b}{10\sqrt{3}};\ f = \frac{4b}{10\sqrt{3}}.$$

The line of unaltered direction is then given by—

$$\tan z = \frac{f - e}{b} = \frac{1}{2\sqrt{3}} = \tan 16^\circ\, 4'.$$

In the case of finite strain it has been shown that this angle preserves its initial value unchanged: so that if $b = -1, f - e = -0.2887$. Since also $e = -f/4$, the following is a consistent set of displacements for $\varphi = 30^\circ$:

$$b = -1;\ e = 0.0577;\ f = -0.2308;\ g = e.$$

Knowing the displacements, the corresponding values of ν and ω may be determined as has been shown in the earlier part of this paper. If these angles only are required they may be found from the following formulas. For any value of b when Poisson's ratio obtains—

$$\tan \omega = \frac{\sqrt{(2 - 3e)^2 + b^2} - \sqrt{25e^2 + b^2}}{2\sqrt[3]{(1 + e)^2 (1 - 4e)}};$$

$$\tan 2\nu = -\frac{2b(1 - 4e)}{(1 - 4e)^2 - (1 + e)^2 - b^2}.$$

For the present displacements the formulas give—

$$\omega = 28^\circ\, 43';\ \nu = -22^\circ\, 37'.$$

For the spacing of the two possible sets of fissures, therefore—

$$w = l \cos(\omega \pm \nu) = (1 - 4e) \cos(\omega \pm \nu),$$

which for this set of displacements gives 0.765 and 0.481.

Supposing that both systems of fissures form, the following diagram (figure 10) shows their disposition at the moment of rupture.*

* *Example for* $\phi = 60^\circ$.—It may be of interest to some readers to give a second example of a similar strain. In the diagram, figure 11, the force is supposed to act at 60° to the plane of support. If, also, $b = -\frac{1}{2}$, the following values result: $e = 0.0866$; $f = -0.3464$; $g = e$; $\varpi = 36^\circ\, 35'$; $\omega = 32^\circ\, 4'$; $\nu = -16^\circ\, 32'$; $\mu = -32^\circ\, 34'$; $h = 0.9172$; $A = 1.236$; $B = 0.575$; $C = 1.087$; $D = o\,d = 0.869$; $w = 0.630$ or 0.432. The range for one set of planes of maximum tangential strain is 0° 24′, and for the other set 16° 26′.

It is apparent from the formulas that e and b fully determine ω, ν and w. It is also true that if the two values of w and the angles between the

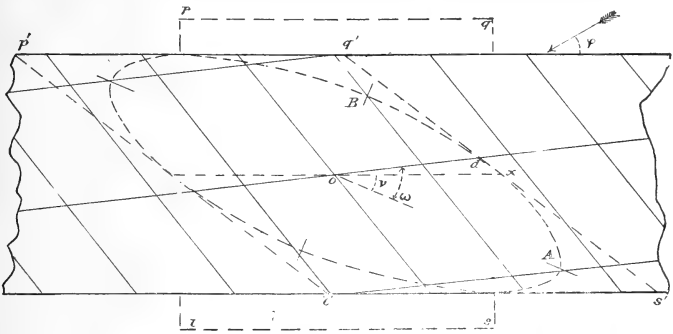

FIGURE 10.—*Results of Rupture by Pressure at 30° to fixed Plane.*

It is assumed that $f = -4\,e$ and that $b = -1$. Thus $e = 0.0577\,g$ and $f = -0.2309$; $\varpi = 31° 20'$; $\omega = 28° 42'$; $\nu = -22° 37'$; $\mu = -51° 19'$; $h = 0.951$; $A = 1.562$; $B = 0.521$; $C = 1.058$; $D = 0.926$; $w = 0.765$ or 0.481. The range for one set of planes of maximum tangential strain is 0° 41′ and for the other 28°.

cracks (or $2\,\omega$) were known by observation, the displacements and the value of φ could be deduced. The two values of w would in such a case enable one to find ν and e, while, when these quantities are ascertained,

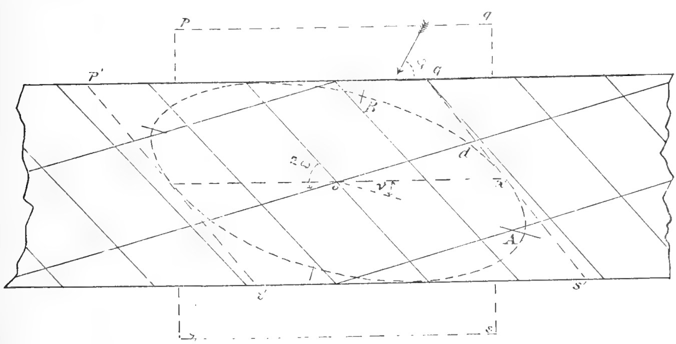

FIGURE 11.—*Results of Rupture by Pressure at 60° to fixed Plane.*

the formula for $\tan 2\,\nu$ will give b. Finally $\tan \varphi = b/10\,e$. But to determine the direction of the force in this manner it must be shown that

the mass was rigidly supported and that it was subject to no lateral constraint. Thus great caution must be exercised in applying this or any similar method to geological occurrences.*

Distortion on Planes of maximum Strain.—It has already been pointed out that the planes of maximum strain are not in general undistorted planes. Consider one of the planes making an angle $\omega + \nu$ with the fixed plane and inquire what ellipse on this plane would answer to a circle of unit radius in the unstrained solid. Prior to strain this material plane made an angle ϖ with that radius of the sphere which ultimately forms the minor axis of the ellipsoid. This radius also originally made an angle $-\mu$ with $o\,x$. Hence it is easily seen that the original angle of the plane to $o\,x$ is $90° - (\varpi - \mu)$.

If y is the original position of the extremity of the unit radius drawn on the intersection of this plane with that of $x\,y$—

$$y = cos\,(\varpi - \mu).$$

If y' is the corresponding ordinate after strain—

$$y' = (1 + f)\,cos\,(\varpi - \mu).$$

If the altered length of this radius is denoted by D, its value is given by—

$$D = y' / sin\,(\omega + \nu) = \frac{(1 + f)\,cos\,(\varpi - \mu)}{sin\,(\omega + \nu)}.$$

It is easy to see that D is in general less than unity. Were the strain plane and undilational, D would be unity, and this case is realized in simple scission (or shearing motion), which may be tolerably frequent among rocks. For a simple shear D would also be unity, but this is a strain probably seldom realized. Whenever a compressive strain is accompanied by two shears the radius in question undergoes contraction and is less than unity.

On the other hand, the unit radius parallel to $o\,z$ is elongated to $1 + g = 1 + e = C$ by an inclined force.

Thus the ellipse on a plane making an angle $\omega + \nu$ with $o\,x$, whose major axis is C and whose minor axis is D, corresponds to a circle in the original mass. The strain involves a compression in the direction of $\omega + \nu$ and an elongation in the direction $o\,z$.

* *Lateral Constraint.*—If a mass were not only supported on a rigid foundation but confined by rigid walls perpendicular to the fixed foundation and parallel to the horizontal component of the force, the strain is also easily calculated on Poisson's hypothesis. Evidently $g = 0$, and it is easy to see that $f = -3e$. Of course, b retains the same value as if there were no lateral constraint. I am not aware that any particularly interesting results arise in this case, which differs from plain undilational strain only in the fact that there is cubical compression. It applies to Mr Sharpe's theory of slaty cleavage.

Various Results of Strain.—In the foregoing pages a theory of slow rupture has been presented, which will be supplemented a little later by considering the possible effect of vibration in those cases in which the rupture is sudden. Observation seems to indicate that many rocks have been strained to the breaking point so gradually that the theory developed is applicable.*

In applying the results reached to the elucidation of geological phenomena the physical character of the rock must be carefully considered. Some rocks when strained with moderate rapidity approach in behavior the ideal, elastic, brittle, non-viscous solid. In such cases an inclined pressure will produce two systems of cracks such as those illustrated in figures 10 and 11. If the mass is held in the strained state, so that the fragments have no opportunity to recoil, the direction of the force may then be inferred approximately by mere inspection. The plane in which it lies will be perpendicular to the systems of fissures. Its direction will intersect the obtuse angle made by the fissures, and it will make a smaller angle with the short side of the parallelogram of cracks bounding a column of the rock than with the long side. The direction of the force can be calculated exactly from the lengths of the sides of the parallelogram and the angle between them, if Poisson's hypothesis is assumed.

If the rock is viscous but not plastic (or if it is strained under such conditions as to bring the viscosity into play, but not to keep the rock for a considerable time in a state of strain exceeding the elastic limit and falling short of the ultimate strength), the effect of the viscosity on the long sides of the parallelogram will be far greater than on the short sides, because of the difference in range of the two planes of maximum tangential strain. Hence fissures will form only in the directions of the short sides of the parallelogram and the rock will be divided into sheets.

If the conditions are such as to develop both the viscosity and the plasticity of the rock-mass, flow will tend to take place parallel to the short side of the parallelogram because of the inferior viscous resistance. If the plasticity is sufficiently great, the strain will not manifest itself as rupture in this direction, but merely as plastic deformation. If the plasticity is not sufficient to prevent all rupture, it will at least diminish the amount of rupture needful to relieve the strain, and there will be mingled effects of deformation and rupture.

These mingled effects might consist either in a wider spacing of this set of fissures or in the distribution of short cracks through the mass. Of these the latter seems the more probable. The area corresponding to

*Striking instances of the rupture of cast iron blocks are depicted in the frontispiece of Todhunter's History of Elasticity. In a general way they accord with the theory developed in the text; but the blocks employed were too slender to give the full system of fissures demanded by the theory for slabs of moderate thickness and great area.

one parallelogram of the figures must receive a certain amount of relief, and if this is not entirely accomplished by flow it must be completed by rupture; but a rupture at each end of the parallelogram would relieve the strain without the help of flow. Thus it appears most logical to suppose that in such cases short "close joints" will be distributed through the plastically deformed mass, excessively minute variations in the resistance of the material determining their precise disposition.

The set of planes corresponding to the long side of the parallelogram cannot behave in the same way as those already discussed. This set sweeps through the mass so rapidly that there is no time for flow of considerable amount to take place. Hence, if they receive expression at all, it must be as sharply cut fissures or as "master joints."

Theory of Slaty Cleavage.—In considering what properties would be exhibited by a plastic, viscous rock which had been rigidly supported and subjected to a pressure inclined at a moderate angle to the plane of support, it is difficult to see how the mass would differ from true slate. The relative tangential motion along the set of planes which eventually makes an angle $\omega + \nu$ with the plane of support would inevitably manifest itself as a cleavage, alternating in some cases with close jointing. In the direction of $o\,z$, or perpendicular to the plane of the figures 10 and 11, this cleavage would be invariable. In the direction $\omega + \nu$ the cleavage would be confined to a very small angle, less than one degree in the examples given above. Thus the mass would cleave very sharply along lines parallel to $o\,z$, less sharply along $\omega + \nu$. Expansion would take place parallel to $o\,z$, while contraction would take place in the direction $\omega + \nu$. This contraction might be accompanied by a puckering of the cleavage surfaces, because the cleavage planes formed at the inception of strain would be still further contracted as strain progressed. The amount of relative distortion in the directions $o\,z$ and $\omega + \nu$ would vary with the direction of the force and the intensity of the strain. The only case in which there would be no distortion on the cleavage plane occurs when the force is parallel to the fixed support. All of these peculiarities of this strain are characteristic of slate, and they seem to cover all of the principal properties of that much-debated rock. I shall return to the comparison of properties in a later portion of this paper.

Influence of Shock.—Although the preceding discussion shows how sheets of rock may be produced by the action of orogenic forces, I am not satisfied that all fractures are produced in this way. There seem, in fact, to be instances in which the spacing of more or less nearly rectangular fissure systems is closer than can be accounted for on the assumption that the fissuring is of minimum amount.

If pressure is applied so rapidly that a considerable shock attends rupture, a corresponding quantity of energy will remain in the fragmental mass in the form of vibrations. These vibrations will take place along the lines of unaltered direction, making an angle z with $o\,x$. In the extreme case of scission this direction is also that of the lines of maximum tangential strain. In every other case the vibrations will occur at an acute angle to the planes of maximum strain, and in no instance will they be perpendicular to these planes.

At the instant when the rupture takes place the whole mass is strained, in one or more directions, to the limit of endurance. Rupture and the inception of waves of compression are simultaneous, and these waves are propagated from the surfaces of primary rupture, but not perpendicularly to them. The waves must interfere and, where they intensify one another, there must be resultant shearing couples in the direction of the planes of maximum tangential strain. These waves must be propagated at the same rate that relief of pressure takes place, a rate dependent upon the properties of the mass. If, then, the waves are of considerable amplitude, it appears to me that on those surfaces at which they reinforce one another, they must intensify the strain beyond the limit of endurance.

Thus there seems sufficient reason to believe that a pressure very rapidly applied, producing primary ruptures attended by shock, will be immediately followed by secondary ruptures in the same direction as the others at intervals dependent upon the wave length of the impulse. In much the same way a high explosive shatters a rock far more than black powder.

A phenomenon of which no explanation has been offered in this paper is that of thick slates and of those flags which are to be considered as very thick slates. These, though cleavable to a certain thinness, are not capable of further splitting. Such rocks indicate a flow which is not uniformly distributed through the mass, but, on the contrary, passes through maxima at intervals corresponding to the thickness of a slate or flag. It is possible that at the inception of strain such masses were in a state of tremor so intense that the interference of waves determined surfaces along which flow began. These surfaces would be weakened by the flow, and further strain would be distributed among them rather than over the intervening solid sheets. Effects of a similar kind are produced on a pile of sheets of paper, such as "library slips," resting on an inclined, cloth-covered table which is jarred by rapid blows.

The question would seem to be one of the direction and intensity of the vibrations rather than of their existence. The tendency of rectilinear motion to pass over into molar vibrations of rapidly decreasing period is so strong as to make it most improbable that such a distortion as is in-

volved in the formation of slate should ever be unattended by vibrations of sensible amplitude.*

Though this hypothesis of thick slates seems probable enough, I am not able to offer a detailed explanation of the process or to show under what conditions thick slates would form rather than thin ones.

Secondary Action on ruptured Rock.—It often happens that the pressure which causes such systems of fissures as have been treated above is not fully relieved by these ruptures and the small relative movements inseparable from rupture. If pressure continues on the divided mass the results will vary with circumstances. When the pressure is oblique and the mass is divided only into sheets, faults of considerable throw may take place. I have previously discussed the distribution of motion in such a system.† It appears from the present investigation that a simple fault arises from pure scissive stress, while distributed faults are due to pressure combined with scissive stress, or, in other words, to oblique pressure. Thus a distributed fault is much the more general case and, in my observation, much the more common. A solitary fault is an extreme and very special case of a distributed fault.

At the instant of rupture there is very little normal pressure between the sheets or blocks of rock, but as rotation progresses the pressure tends to increase. Extensive movements are therefore accompanied by a forcible grinding of the fragments against one another. At first the stresses called into play are but little inclined to the surfaces, and the result is often to produce slaty structure close to the surfaces of the fragments. I have observed very many cases in which large blocks of granite showed slaty cleavage close to the bounding surfaces which had evidently been produced in this way. The cleavage was certainly in part due to close jointing, but in most cases the cleavage faded out at some little distance from the edge of the mass, and the inner portion of the slaty selvedge must therefore have arisen from strain without rupture (Heim's Umformung ohne Bruch). Such slaty selvedges thus furnish important evidence as to the manner in which slate is formed in nature, evidence entirely accordant with that afforded by experiment.

When the secondary pressure becomes more nearly perpendicular to the faces of the sheets of rock, these may themselves be divided into secondary sheets, and a continuance of the process will reduce the rock to a confused rubble.

Effect of tensile Stresses.—Jointing has been referred to tensile stresses by several authors. It is therefore desirable to examine what effects tensile stress can have upon homogeneous substances. To give abstract

* See Am. Journ. Sci., vol. xxxi, 1886, page 115.

† Geology of the Comstock Lode, U. S. Geol. Surv., monograph iii, chapter 4.

ideas a concrete form, suppose that a hot cube of homogeneous matter were to be cooled from one side only, and that the cooled surface underwent contraction. This contraction would produce tension throughout the cooling surface, excepting at the edges, so that the surface would assume the form of a very shallow dish, as illustrated in the following diagram:

FIGURE 12.—*Contraction of Mass cooling from one Side.*

Since the tension would be zero at the edge, it would clearly be greatest at the center, and here rupture would take place in the surface film when the tension reached the limiting value. The tension at the center might be relieved by cracks of various characters. A single straight crack would relieve it only in one direction, and would, in fact, tend to increase tension in the direction of the crack, because the crack must gape, and its edges would therefore slightly exceed its median line in length. This form of rupture is therefore impossible under symmetrical conditions. The same objection applies to two cracks forming a letter T. Complete relief at the center would be afforded either by an X-shaped crack or by one in the form of a Y. Of these, the latter has the smaller total length for a given intersected area. Now, the cracks will clearly form in such a manner as to afford the greatest amount of relief per unit length of crack, and hence the rupture will take the shape of the letter Y. This will afford total relief at the center and partial relief at surrounding points. This relief, under symmetrical conditions, must be equally distributed, and therefore the three cracks must make with one another angles of 120°.

This simple inference is confirmed by observation. Thus, if one allows a vessel containing melted wax to cool slowly, an excessively thin transparent film forms on the surface. Then a minute opaque Y becomes visible near the center. This is due to the cracking of the film and the great acceleration of the process of solidification on the sharp exposed edges. So, too, a slight blow on glass often produces cracks in the same shape. Cracks in asphalt pavements frequently show a tendency to the same form; so do those in drying mud, and many of the divisional surfaces in columnar lava meet one another at angles approaching 120°.

As the cooling progresses the cracks must extend from the center; but the longer they are the less is the relief which they afford in the circle circumscribing their extremities and, unless the cooling area is small,

other cracks must form. Either, then, rupture will take place at new centers or the original cracks will branch at their ends. A greater amount of relief for a given length of crack will be afforded by the latter method. The branches will be thrown off at angles of 120° for the same reason that the first cracks formed this angle. As the process continues the branching will be repeated, and it is evident that the surface will be divided into regular hexagons. The more slowly the cooling progresses the smaller will be the tension in the exposed surface and the larger will the hexagons be.

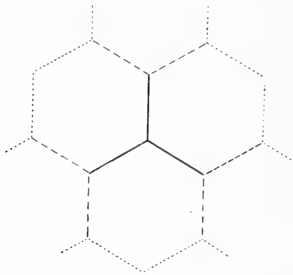

FIGURE 13.—*Primary tension Cracks.*

In some cases tension may accumulate in one of the hexagons after division to such an extent that a secondary rupturing takes place. This too will begin by three radiating cracks at the center, and these must be perpendicular to the greatest tensions or to the lines joining opposite angles of the hexagon. They will thus divide the hexagon into inequilateral pentagons, and the secondary fissures will be at right angles to the sides of the hexagon.

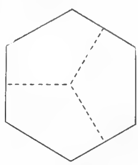

FIGURE 14.—*Secondary tension Cracks.*

The tensions are due to stresses acting at the isothermal surfaces and tangential to them. Hence, if the mass cools faster at one side than at the other, the resulting columns will be curved and will everywhere be

perpendicular to the isotherms for which the tensions reach the limit of cohesion.

Each of the columns cools as a separate body, and if the following figure represents a vertical section of one of them, the dotted lines approximately represent the position of the isotherms. In the separate column the tension will be greatest at the edges, because these, exposing a great surface per unit volume, will chill most rapidly. When the column has reached a sufficient independent length, the tension on the edges will be so great that they will rupture perpendicularly to the isotherms. These ruptures will cut inward from the sharp edges and divide the columns laterally by cup-shaped surfaces. The interval between these vertical subdivisions of the column depends on the amount of tension which the mass can stand without rupture, and will evidently be of the same order as the diameters of the columns themselves.

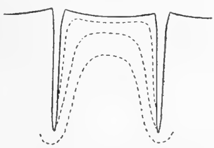

FIGURE 15.—*Cooling of Columns.*

The foregoing deductions all correspond very closely to the phenomena of columnar structure in massive rocks. Basalts, diabases, and the like, however, are far from being homogeneous, and it is surprising that the surfaces of the columns should be so smooth. If one were to cut a suitable bar of diabase and break it by tension in a testing machine the fracture would certainly be much rougher than the side of a diabase column. This seems to be accounted for, at least in part, by the fact that rupture probably takes place immediately after solidification of the groundmass and before any difference in rate of cooling between the embedded crystals and the groundmass has locally weakened the cohesion of the latter. When masses of mud in drying out split into columnar fragments, the torn surfaces are less smooth and the divisions less regular.*

REVIEW OF THEORIES OF SLATY CLEAVAGE.

Why Needful.—So little attention has been paid by geologists to systems of faulted fissures that the field may be said to be a new one. I know

* There is an intimate connection between the problem of columnar structure and that of the division of space with minimum partitional area. See an investigation of the latter subject by Sir William Thomson (Lord Kelvin), Mittag-Lefflers Acta Math., vol. 11, 1887–'88, p. 121, and Plateau, Statique des Liquids, vol. 1.

of no serious attempt to deal with the mechanics of the subject prior to a paper already cited, in which I discussed those cases of rupture in which the deformation could properly be regarded as infinitesimal. The results there reached have been born out by further observation. In this paper the investigation has been extended to cases of faulted fissures in which deformation of the rock is finite, and the conclusions certainly accord with very numerous observations which I have made in the Sierra Nevada of California and elsewhere, nor are any facts known to me which seem in conflict with the theory presented.

On the other hand, jointing and slaty cleavage have been much discussed. Some authorities regard them as closely allied, while others refer them to radically different causes. Many experiments have been made on slaty cleavage and various theories have been propounded to account for it. The theory here advanced is new, and I may say that it is a surprise to myself. I have long felt that the theory which refers slaty structure to a pressure perpendicular to a fixed plane of resistance and parallel to two lateral constraining planes was unsatisfactory. The combination seems too artificial. The chances against its occurrence seem too large when the frequency of slaty structure is considered. I did not anticipate, however, that analysis would show so large a range of conditions under which slaty structure might result, and I entertained the idea that if a slanting force produced slaty cleavage the force would slant in the direction of the grain of the slate. I have been led by purely algebraical reasoning to believe that the force may be inclined to the fixed plane within very wide limits, covering at least 60°, and that in all cases the plane of the force is at right angles to the grain of the slate.

Under these circumstances it is absolutely necessary to pass in review the principal theories hitherto advanced and to compare the new theory with the results of experiment and observation.

Origin of Jointing.—Joints are commonly nearly plane surfaces dividing rock masses and arranged in groups, the members of which are parallel to one another. Fault fissures are also frequently arranged in similar groups, and show similarly flat surfaces, the term joint being employed when the amount of relative motion on the divisional surfaces is imperceptible or is regarded as negligible. Jointing has been referred to tensile stresses by distinguished authorities, including W. Hopkins, but the correctness of this reference has been questioned. Thus, Professor W. King,* after special investigation, stated his opinion that, in their original condition, the walls of joints were in close contact, and protested against the classification of columnar structure with jointing. Mr G. K. Gil-

* Trans. R. Irish Acad., vol. 25, 1875, p. 605.

bert* also draws a contrast between the divisions of a mass due to shrinkage cracks and those known as jointing.

There can be no question that jointing is due to mechanical causes; for joint planes cut through conglomerates with almost the same regularity that they divide the most homogeneous rocks. They must, therefore, be due either to tensile stresses or to compressive stresses. In the former case the joints must gape when first formed. I am fully satisfied that Professor King was correct in asserting that the surfaces are usually in close contact immediately after rupture. In very many cases dislocation has taken place on jointed surfaces and, where this has occurred, any irregularity in the surface will force the walls asunder.

It has been shown in the preceding pages that the columnar structure of lava is easily accounted for, but I know of no way in which such a system of divisions as occurs in jointing can be accounted for by tension.†

On the other hand, it is not difficult to show that most of the phenomena of joints are fully accounted for by pressure, direct or inclined; but to this statement there is one exception. If joints are produced by pressure, they are due to a tendency of the rock to move in opposite directions along the joint plane; or, in other words, to a tendency to faulting. Hence, if pressure is the cause, there is no distinction, excepting one of degree, between joints and faults.

There is no doubt whatever that faults are often met with on joint planes, yet this association is no proof that the two phenomena are not, as they have often been assumed to be, independent of one another. But the study of many thousand divisional planes which would certainly be regarded as joints by almost every geologist has led me to the conclusion that the jointing and the faulting are concomitant. The faults are often extremely small, but it is very rarely that in a system of joint planes throws of an eighth of an inch or less cannot be detected; and where the rock is hard, slickensided surfaces will be found even when the relative movement is much less than an eighth of an inch. Few geologists have been in the habit of looking for faults of such tiny dimensions, and I believe that the distinction between faults and joints has arisen from this omission. Partings due to tension would be free from slickensides.

It might be thought that a refutation of this conclusion is to be found

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*Am. Jour. Sci., vol. 24, 1882, p. 50.

†Divisional surfaces produced by pressure differ from those produced by tension in a manner which is distinguished even in ordinary parlance. Rupture under tension is only another name for *tearing*, while division under pressure always involves as an essential feature that sort of *cutting* which is performed with scissors or shears. Thus the very similes employed in describing rock fractures often indicate an instinctive perception of the mechanical processes involved, even when an attempt is made to reconcile phenomena with a less natural theory.

in the fact that joints frequently die out; but faulted fissures, even those carrying important ore deposits or considerable dikes, also die out. Nevertheless, the dying out of joints shows that the movements involved must at some points be microscopic, and indeed submicroscopic.

M Daubrée has succeeded in reproducing jointed structure in the most striking manner by pressure on mixtures of beeswax and resin. The following cut is copied from his experimental geology and explains itself:

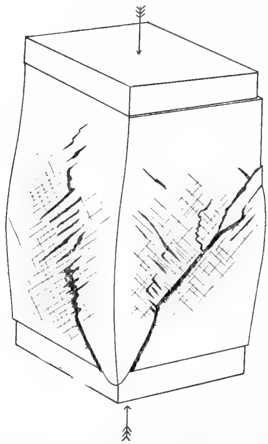

FIGURE 16.—*Daubrée's Experiment on Crushing.*

Here, as in nature, there are joints which die out, but they are associated with faults of measurable throw. The system of divisions is precisely that deduced for a direct pressure in the earlier portions of this paper from the theory of strain.

Still another lesson can be learned from this experiment. The sides of the crushed column bulge in such a manner as to show that plastic deformation has taken place as well as rupture. Now since these ruptures can be conceived only as relative tangential movements pushed to the limit of cohesion, it seems to me clear that the plastic deformation also must consist in relative tangential movement, and, indeed, in the same directions as the joints, but not reaching the limit of cohesion. If one inquires what is the effect of this plastic movement on the structure of the mass, one can only reply that it must be something very analogous to schistosity.

Others have made experiments with similar results. It is well known that cast iron, building stone and similar substances, crushed in testing machines, do not yield on planes parallel to the support, but at angles approximating to 45°, when the slabs are broader than they are thick. Not all of the cracks pass through the masses experimented upon. The slabs are somewhat deformed, and, in short, the phenomena are strictly comparable with those of M Daubrée's experiment, though less brilliantly illustrated.

Jointing and Cleavage.—Many geologists have been struck by the intimate manner in which jointing and cleavage (whether schistose or slaty) are associated, and there seems to have been a growing tendency to assert or imply a relationship between them, even in spite of an assumed theoretical difference in origin. Professor William King advanced the hypothesis in 1857 that slaty cleavage was derived from jointing, the jointed surfaces having been welded under pressure. This conclusion, indeed, has not, to my knowledge, been adopted by any other observer; but rejection of the conclusion does not imply rejection of the facts upon which it was based—viz., that dislocated jointing occurs "developed to a degree of fineness bordering on that of mineral cleavage," as at Carragrian, near Galway, and the occasional alternation of joints with parallel slaty cleavage.* Professor A. Heim distinguishes cleavage due to microscopic dislocated joints from cleavages unattended by joints, or true slaty cleavages. Of these he makes two classes: "micro-cleavage," consisting in a flattening of the component grains of the rock, and cleavage due to the re-arrangement by pressure of previously existing scales in positions more and more nearly perpendicular to the line of pressure. All three varieties are associated so intimately, according to Heim, as to be found in one and the same thin section. Even in cases of pure micro-cleavage relative movement without fracture in adjoining cleavage planes may be detected.† M Daubrée speaks of "the surfaces of slipping which produce schistosity;" ‡ Dr H. C. Sorby has described cases of discontinuity on a microscopic scale which lead to cleavage; Messrs Geikie, Peach and Horne describe fluxion structure and shearing as productive of schistosity and highly cleaved rocks, the planes of cleavage being parallel to the thrust plane,§ and other similar observations could be cited to show that relative tangential motion and slaty cleavage are at least most intimately associated in nature.

Phenomena of slaty Cleavage.—Workers in slate distinguish not only the cleavage faces, but also "side" and "end." Most slates can be split only

* Trans. R. Irish Acad., vol. 25, 1875, p. 612, *et passim*.

† Mech. der Gebirgsbildung, vol. 2, 1878, pp. 54–56.

‡ Études Synthétiques, 1879, p. 321.

§ Nature, vol. 31, 1884, pp. 29–35.

in one direction, which appears to be usually that of the dip of the slate in its original position. A block of slate thus bears some analogy to a block of wood, so far as its fissility is concerned. In some cases, however, slates are said to split equally well from any edge of a block. Fossils occurring in slate are usually distorted, and numerous measurements of these fossils have been made for the purpose of ascertaining in which direction the greatest elongation and contraction have taken place. As might be expected, these measurements do not accord very closely, for it is difficult to expose a fossil in such a manner that all its dimensions are accessible without obscuring the relations of these dimensions to the dip and strike of the slate. Sometimes there seems to be no relative distortion in the plane of the cleavage. In other cases the fossils are greatly distorted in the cleavage plane, the longer axis coinciding with the dip.

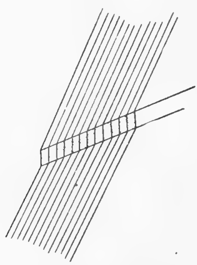

FIGURE 17.—*Steps in Slate.*

It is frequently asserted that the greatest elongation of the fossils is always in the direction of the grain of the slate, and the greatest contraction perpendicular to this direction. This implies that there has been no tangential movement among the laminæ, or that there is no fluxion structure and no close jointing or "Ausweichungsclivage" in the rock; for in any such case the axes of the strain ellipsoid must fail to coincide with the dip, the strike, and the perpendicular to the cleavage. Now these structures are known to be frequent in slaty rocks and distinguishable from true, slaty cleavage only under the microscope. The deductions from the measurements of the fossils can therefore be only approximately true. I have myself seen fossils in slate in which fluxion structure was plainly manifested, in my opinion, and in that of an eminent paleontologist whom I consulted. Slaty developments of crystalline rocks are by no means unknown, and these are closely allied to

schistose rocks, in which crystals have certainly undergone distortions involving fluxion phenomena.

In slate quarries there are usually "steps" produced by the presence in the slate of strata differing in lithological character from the bulk of the rock. The cleavage is deflected by these strata, and when they are sharply defined the deflection is also sharp. When the cleavage is at right angles to the stratification the deflection is nearly or quite imperceptible, and it seems to be maximum when the angle approaches 45°. The illustration on the opposite page is taken from Mr Alfred Harker's admirable memoir on slaty cleavage.*

All of the above phenomena must of course be accounted for in any satisfactory theory of slaty cleavage.

Theories of slaty Cleavage.—The earlier geologists naturally associated slaty cleavage and mineral cleavage, and ascribed both to the same or similar causes. Professor John Phillips was the first to offer a mechanical explanation.† In doing so he was prudently indefinite. He described the distortion as a "creeping movement among the particles of the rock, the effect of which was to roll them forward in a direction always uniform over the same tract of country." This language has been interpreted as equivalent to the hypothesis of a simple "shearing motion," but it will by no means bear this limited construction. Phillips had in mind a rotational strain and a fluxional structure, but his paper contains nothing to indicate the absence of forces acting perpendicularly to the cleavage planes. He neither denies nor asserts the coöperation of such forces. He also says nothing to indicate that his theory was applicable only to heterogeneous matter, and it is fair to conclude that he supposed that slate might be produced from homogeneous substances.

Mr D. Sharpe explained the structure as due to the contraction of rock in the line of pressure and a partially compensating elongation at right angles to it. This strain is one of two dimensions, and consists of a simple shear (not a shearing motion) with a cubical compression. The fissility produced he referred to the fact that a fracture perpendicular to the direction of pressure would run along the flattest faces of the component grains and meet the smallest number of them. This explanation implies that the mass is heterogeneous, and that the adhesion between the component particles is smaller than the cohesion within the particles.‡

Dr H. C. Sorby, to whom geology owes so great a debt for the introduction of the microscope as an instrument of lithological research, natur-

* Brit. Assoc. Ad. Sci., 1885, p. 813. Mr Harker's paper contains very full citations of the literature of slate, and the reader who cares to pursue the subject is advised to consult it. No attempt is made in the present paper to give a full bibliography.

† Brit. Assoc. Rep., 1843, p. 61.

‡ Q. Jour Geol. Soc., vol. 5, 1849, p. 128.

ally attacked the question from a microscopical standpoint. He found that the mica of the slates was largely concordant with the cleavage and referred the fissility to the effect of direct pressure in deflecting mica scales toward a direction at right angles to the line of pressure.*

This theory is supplementary to that of Mr Sharpe, and it is to the united effect of the flattening and deflection that slaty cleavage is now usually ascribed.

Mr A. Laugel assumed on the authority of Sharpe that the strain consists of a simple shear. He pointed out the fact that in a simple shear in a homogeneous mass the planes of least resistance (or, as I have called them, of maximum tangential strain) stand at an angle with the axes of the shear dependent upon the deformation. In the notation of this paper † he reached the result $tan^2 \varpi = B/A$. He gave no proof of this, however, and did not explain how the double cleavage implied in this equation of the second degree could be reduced to the simple cleavage of slate.‡ In my opinion he was on the right path to a sufficient explanation, but he certainly did not achieve it.

Professor John Tyndall's famous experiments on slaty cleavage in wax in a direction perpendicular to the pressure were published in 1856.§ He dissented from Sorby's theory, regarding his wax as homogeneous, and finding that the intermixture of scales rather interfered with than promoted cleavage. Dr Sorby replied to Tyndall, citing experiments of his own on clay mixed with mica scales and pointing out that wax contains prismatic crystals; so that, in his opinion, the wax must be considered as composed of elongated elements capable of re-arrangement by pressure, according to his theory.‖

Mr Daubrée found that clay without mica scales when extruded through a small opening assumes a schistose structure, the lamination being close in proportion as the material is more finely divided.¶ He also obtained evidence of schistose structure in flint glass, softened by heat and forced through an opening. In this case at least there could be no question that the resultant structure was independent of heterogeneous particles.

Dr Sorby made an addition to his theory of slaty cleavage in 1880. In his original theory it was assumed that the mica before compression was distributed through the mass without any order. As a matter of fact, the mica scales in shale are, for the most part, parallel to the bedding.

* Ed. New Phil. Mag., vol. 55, 1853, p. 137.

† See formula (9), p. 33.

‡ Comptes Rendus, vol. 40, 1855, p. 978.

§ Phil. Mag., vol. 12, 1856, p. 37.

‖ Phil. Mag., vol. 12, 1856, p. 127.

¶ Géol. Exp., 1879, p. 413.

In certain cases, however, he observed that the bedding was almost obliterated by the disturbances due to the pressure. The supplementary hypothesis is that the preliminary effect of pressure is to give the mica an irregular distribution, the final effect being to reärrange the mica scales in the planes of cleavage.*

Objections to the Hypothesis of Heterogeneity—In my opinion, there are the gravest objections to the hypothesis that slaty cleavage is due to the lack of homogeneity of a rock mass which has been subjected to the action of force. Neither Tyndall nor Daubrée found that the presence of scales promoted schistosity, but just the reverse. The wax employed by Tyndall may have consisted largely of prismatic bodies; but before pressing his wax he softened it, making these bodies, as well as their groundmass, very plastic. He also kneaded the mass, so that the component particles must have welded. Even if every one of the prisms had assumed a horizontal position, there is no reason to suppose that the cohesion between them and the groundmass of the wax was feebler than that between the different portions of any one prism, or that any schistosity, at all approaching slaty cleavage, would have resulted. Similar remarks apply to Daubrée's experiments on clay.

Dr Sorby's supplementary hypothesis is suggestive in the same connection. All geologists will grant that disturbances are sometimes such as nearly or quite to obliterate the bedding of shales, but none will assert that this is a condition of slaty cleavage. We all know that the bedding is often most distinctly preserved in masses of roofing slate, and that the lamination is not infrequently fairly regular. In such cases it seems to me impossible to contend that the mica scales originally concordant with the bedding have been stirred up in such a manner as to be distributed at all angles through the mass. Again, there are many somewhat indurated shales not affected by slaty cleavage in which there are countless mica scales, nearly all of them concordant with the bedding. If the distribution of mica scales constituted the fissility called slaty cleavage, such beds should split like slate in the planes of bedding. Such beds are sometimes fissile to a certain extent, but cases in which this fissility could be mistaken for slaty cleavage are very rare, if, indeed, any are known. When rocks split along their lamination at all like slate, geologists expect to find, and usually do find, that the rock possesses true slaty cleavage coinciding locally in direction with the planes of bedding, but superinduced upon and independent of bedding.

Similar objections apply to Mr Sharpe's theory of the flattening of the rock components. It affords no explanation of Professor Tyndall's experiments, and were it correct some fine-grained sandstones, at any rate,

* Q. Jour. Geol. Soc., vol. xxxvi, 1880, p. 73.

would cleave along the bedding exactly like slate, which does not accord with observation.*

It appears to me, therefore, that no theory of slaty cleavage will be satisfactory which does not apply to the case of homogeneous matter.

Analysis of Experiments.—Slaty cleavage has been produced artificially in several different ways. Plastic substances compressed between rigid masses exhibit such cleavage; so too do plastic masses extruded through small openings; poor qualities of iron or brass when drawn to wire often show thin splinters, indicating the presence of cleavage; metals, pastry and clay rolled out into sheets show similar fissility, and, as Professor E. Reyer has pointed out, the bruise produced on soft rocks by a slanting blow with a pick exhibits a like structure.†

These cases seem very different, but they must have common features, unless, indeed, slaty cleavage is due to essentially diverse causes. Most of the mechanical operations indicated are very complicated, but their common features may be reduced to simple terms by considering a very small cubical portion of the mass before distortion and inquiring how it is affected by strain.

FIGURE 18.—*Origin of Cleavage in Wire.*

If one end of a wire is filed to a flat surface perpendicular to its axis, and the wire is then drawn through two or three successive holes of a draw-plate so that the flat end is the last to come through, it will be found that this end has become concave. If one considers a small cube in the undistorted wire, not on the axis, it is clear that this cube will be converted into an oblique parallelopiped, as is illustrated in the foregoing diagram, showing the wire in section.

The concentric layers of the wire move upon one another much like the joints of a telescope. The little cube is elongated in the direction of the axis, its height is diminished, and its right angles in the plane of the axis are converted into acute or obtuse ones. It is clear that the sphere which might be inscribed in the small cube has been distorted to an ellipsoid, the major axis of which becomes more and more nearly horizontal as the strain increases. The strain is thus a rotational one, and, according to the theory of strain set forth in this paper, a cleavage should be developed nearly in the direction of the axis.

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* See p 74.

† Theoretische Geologie, 1888, p. 577.

If a bar were substituted for a wire, and slots for the circular openings of the draw-plate, the strain would be exactly equivalent to that produced by an inclined pressure acting on a rigidly supported cube. It cannot be doubted that in such a case the end of the bar would also become concave, and that evidences of schistosity would appear.

When a plastic mass is extruded through a small opening, whether circular or rectangular, the action is very similar to that involved in drawing wire, excepting that the external force is a pressure instead of a tension. The friction on the moulding surface delays the motion of the external layers relatively to the internal layers, and so-called fluxion structure results. In the following diagram it is plain that a cube of the plastic mass at *a* would become an oblique parallelopipedon at *b*.*

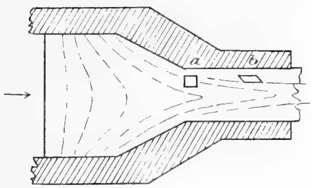

FIGURE 19.—*Development of Cleavage by Extrusion.*

When an oblique blow is struck with a pick the bruise will manifestly show a distortion of a very small cube similar to those already considered.

The case of a direct pressure, such as was employed by Professor Tyndall, seems at first sight very different from the foregoing. To convince myself as to the mechanics of the matter I repeated his experiments, with the following results: † A cake of wax can be compressed to less than half its thickness between glass plates well greased with a heavy oil without bulging of the edges, as shown in figure 20, *a*, *b*. If such cakes are cooled to — 15° C. they show no slaty cleavage, but exhibit a tendency to split at an angle of some 60°, more or less, to the line of pressure. If the plates are not greased, but only wet with water, as in Tyndall's experiments, there is a strong tendency to bulge along the

* M Daubrée, in his Géologie Expérimentale, records striking experiments on this mode of deformation.

† White wax is better than yellow for the purpose of this experiment. To get comparable masses I cast cylindrical cakes at as low a temperature as practicable. These were cooled off and then kept in water at about 40° C. for an hour or more. Below this temperature the wax is too brittle to mould with ease or rapidity. The compressed cakes were cooled in ice and salt. Cakes chilled without preliminary distortion show no cleavage under the hammer or chisel, and crack very like fine-grained basalt.

edges, so that the cake assumes the form of an ordinary American cheese. Cakes compressed to one-quarter of their thickness were very greatly distorted in this sense, as shown in figure 20, *c*. When cooled and struck sharply on the edge with a hammer, they showed slaty cleavage. The character of the distortion of a small included cube follows from the distortion of the mass, and, as appears from the following diagram, it is a distortion similar to that which takes place when a cube is subjected to inclined pressure, as illustrated in figure 6, B, page 56.

The reason for the bulging edges is at once seen to be the frictional resistance between the glass plates and the escaping wax. This resistance, combined with the vertical pressure, gives resultant forces, marked *r r* in the figure, which are not vertical but lie on conical surfaces about the central vertical axis. When this friction is obviated by the use of a lubricant, so that a nearly uniform distribution of pressure is obtained, there is no tendency to relative horizontal motion among the layers, and in a dozen or more trials with lubricators I failed to find any trace of horizontal cleavage. A tendency to cleave is sensible in these cases, but it coincides with the planes of maximum tangential strain as nearly as the imperfection of the surfaces enabled me to judge.

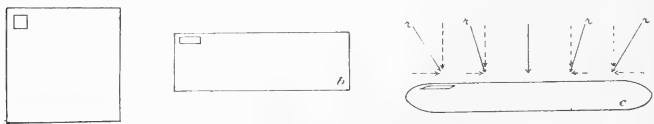

FIGURE 20.—*Development of Cleavage by direct Pressure.*

Thus it appears to me that Professor Tyndall's brilliant experiment has been misinterpreted. He produced slaty cleavage not by a pressure uniformly distributed and vertical to the cleavage planes, but by a system of forces inclined to the cleavage planes.

The effect of rolling metal, clay, or pastry is similar to that of direct pressure combined with lateral friction. A cake of plastic material is reduced to a sheet with bulging edges like figure 20, *c*, and an infinitesimal cubical portion of the mass is distorted as in the other cases.

I am aware of no other ways in which slaty cleavage has been produced artificially. In all of those discussed the distortion attending development of the cleavage is substantially the same. The elementary cube is deformed as it would be by a force inclined to one face of the cube when the opposite face rests upon an inflexible support. In some cases there is lateral constraint; in others there is none. The splinters on rolled metal and pastry seem to show that the cleavage developed is not quite parallel to the surface of the mass.

It might seem as if the varying directions of pressure detected in Tyndall's experiment were geologically unimportant. Granting that the vertical, uniform pressure at first applied to the wax is conically resolved, does it not follow that in orogenic movements also a similar resolution occurs; so that, after all, slaty cleavage is due to a pressure originally uniformly distributed and perpendicular to the cleavage? This query must receive a negative reply.

The reason why the pressure in the experiment is resolved into a conical system of forces is that the bodies between which the wax is squeezed do not themselves yield sensibly. Thus horizontal relative motion attended by friction is brought about. Were these bodies as soft as the wax, they too would extend laterally and the pressure would remain uniformly distributed. It would also produce no slaty cleavage.

In orogenic movements there is seldom any diversity between the resistance of adjoining rock masses approaching the difference between plates of glass and warm wax. Among rocks, therefore, a direct pressure will, as a rule, be distributed with an approach to uniformity, and there will be little or no relative motion between adjoining rock masses in directions perpendicular to the pressure. Hence, also, important masses of slate will not be produced in this way.

Perhaps no combination is entirely wanting in mechanical geology. In artificial cuttings, clay beds underlying harder materials have been known to be squeezed out laterally, and these masses must have been affected like the wax in Tyndall's experiment; but this case scarcely forms an important exception.

In most cases of the geological occurrence of slate there is little direct evidence of the mode of formation, and it is for this reason that the experiments are of so much value. Sometimes, however, the method of formation of natural slate is clear. I refer especially to the slaty selvedges which are not infrequently seen bounding small faults in granite and which have been mentioned under the head of secondary action on ruptured rock. No geologist can doubt that these selvedges are produced by the inclined pressure attending faulting, and it is manifest that the distortion of an elementary cube would be exactly that which so constantly accompanies the artificial production of slaty cleavage. Thus, in some cases at least, natural slate is produced by the same means which are employed in producing artificial slate.

Behavior of included Grit Beds and Fossils.—The theory that slate is produced by a uniformly distributed pressure perpendicular to the planes of cleavage, such as it has been usual to suppose existed in Tyndall's experiment, implies that the strain ellipsoid is an oblate figure of revolu-

tion. In such a slate a fossil which lay in the cleavage plane would simply be flattened. From the observed fact that fossils are frequently, though not always, relatively elongated to a sensible degree in one direction in the cleavage plane, Mr Sharpe inferred lateral confinement as well as vertical pressure.

On the theory of inclined pressure, a fossil would always be elongated in the direction of the grain of the slate and contracted across the grain in the cleavage plane, excepting when the pressure made no angle with the fixed plane. A still greater elongation, however, would take place in the direction of the major ellipsoid axis, called A in this paper, which is at right angles to the grain and makes a large angle with the cleavage plane. That such distortions do exist I have convinced myself by the examination of specimens, but I have not had an opportunity of examining any large collection of fossils from slates with reference to this point.

The relations of beds of hard grit occurring in slate bear a close relation to those of fossils. If such a bed were bounded by surfaces parallel to the plane $x\ y$ (or $A\ B$), the bed would behave either to a vertical or to an inclined pressure as an independent mass. On the currently accepted theory it would develop a horizontal cleavage. On the theory of inclined pressure it would develop a cleavage in a direction between that of the pressure and that of the fixed plane; and this would nearly coincide with the cleavage of the surrounding softer mass, because the direction of cleavage lies near that of constant direction and changes but little during strain. The smaller the angle which the force makes with the fixed support, the smaller would the divergence in the two cleavages be.

"Steps" are produced when a grit bed cuts the cleavage across the grain, the plane of the cleavage in the slate and the surface of the grit bed making an acute angle. The grit is a harder material than the slate, and the cleavage developed in the grit makes a larger angle with the bedding than it does in the slate.

To account for steps according to the theory of inclined pressure one may consider the elementary stresses separately. It has been shown that the shear in the plane $B\ C$ does not tend to produce relative motion on the cleavages. One may therefore suppose the stress, minus this shear, to be applied to the rock first, and this shear to come into action later. Figure 22, a represents a cube in the $y\ z$ plane, with a layer of harder material passing diagonally through it. If a shear and a shearing motion or scission in the $x\ y$ plane are impressed upon this mass, both portions must yield simultaneously, because if the force were insufficient to strain the harder layer, this would protect the surrounding mass from the action of the force. Hence these strains would produce in both masses a cleavage, the traces of which on the $y\ z$ plane would be parallel to $o\ z$, and

the appearance of the mass would be that shown in figure 22, *b*, where the fine horizontal lines represent mere cleavage, not partings. Now let the final shear at right angles to the $x\ y$ plane be applied. It will elongate the mass in the direction $o\ z$ and contract it in the direction $o\ y$. But since the more rigid layer yields to this stress less freely than that in which it is imbedded, the grit bed will rotate more nearly as if it were a rigid mass, and will assume such a position as is shown in figure 22, *c*. In short, the hard layer will be deflected in just the same way that an imbedded scale of mica parallel to it would be deflected. Thus the cleavage in the hard layer will not be parallel to that in the adjoining mass and will form a larger angle to the bed planes.

It thus seems sufficient to suppose the grit bed to have a greater coëfficient of rigidity to account for the phenomena of steps.*

* Dr Sorby's theory of this phenomenon, as stated by Mr Harker, is as follows: "Since the grit yields less than the slate to the compressive force, the total voluminal compression is greater for the slate than for the grit. But near the junction of the two rocks the change of dimensions in the direction parallel to the bedding must be the same for both. Consequently, in the direction perpendicular to the bedding, the slate undergoes a less expansion (or greater compression) than the grit; and the cleavage planes, which are in each rock perpendicular to the direction of greatest compression, will therefore be less inclined to the bedding in the slate than they are in the grit."

This is a very ingenious explanation, but I have not been able to convince myself that it is sound. It depends primarily upon the hypothesis that a large cubical condensation is involved in the production of slate. This certainly does not seem to be the case when slaty cleavage is produced in moist clay or wax, for such substances are probably compressible only to a very minute extent. It also implies that there is a very great difference between the cubical compressibility of the grit and the shale. I know of no good reason to suppose that such a difference exists. The difference in hardness does not imply such a relation, for cast iron, though so much harder than gold, is nearly three times as compressible; but even if it be granted that the relations of compressibility are those demanded, it is not clear that any means is provided of changing the direction of the force in the manner required by Sorby's theory of cleavage.

One may suppose a cubical portion of a rock mass to undergo the pressure needful to develop slaty cleavage without change of volume, and that cubical contraction takes place subsequently. If the mass contains a stratum of smaller compressibility than the remainder, the cleavage on the theory now under consideration would be perpendicular to the direction of the force throughout the mass before cubical contraction occurred. In this stage the mass would have the appearance of figure 22, *b*. The effect of the shrinkage would then be to deflect the slaty laminæ close to the contact in curves with points of inflection at the contact, but to leave the direction of the cleavage at a little distance from the contact unchanged. The appearance after cubical contraction would would then resemble that illustrated in the following diagram:

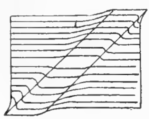

FIGURE 21.—*Effects of Compressibility.*

But this does not represent the phenomenon to be accounted for; so that although the hypothesis of varying cubical compression would explain a change of direction in the surfaces of cleavage at the contact with a gritty bed, it does not, so far as I can see, account for steps.

Conclusion as to Slate.—The fact that slaty structure occurs not only in argillaceous rocks but, though less frequently, in limestone, grit beds, granite and basic eruptives, while it has been artificially produced in wax, clay, metals, dough and glass, throws much doubt on the hypothesis that slaty cleavage is due to re-arrangement under pressure of embedded flakes and grains of matter. This doubt seems confirmed by the fact that although the component grains of many undisturbed shales and sandstones are so arranged that their largest sections lie parallel to the planes of bedding, such rocks do not show any cleavage closely resembling that of slate. Hence a satisfactory explanation must apply to homogeneous matter.

Examination of the experimental methods of producing slaty structure shows that in all cases the distortion of a small portion of the mass is rotational, and is such as would be produced upon a cube resting on a rigid support and affected by an inclined force, with or without the co-operation of lateral forces in the plane of support.

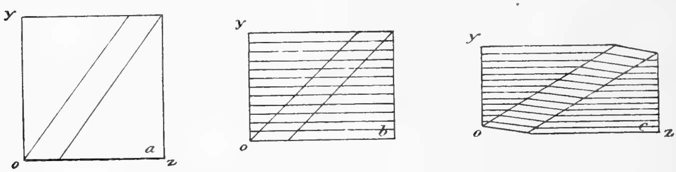

Figure 22.—*Deflection of Cleavage by Grit.*

The theory of finite strain in viscous plastic masses shows that rotational strains of this description should be accompanied by the development of a cleavage. The grain of a mass thus distorted should have an absolutely constant direction parallel to the plane of support and perpendicular to the line of force. Elongation should, in general, take place in the direction of the grain, and contraction at right angles to the grain on the cleavage plane. When, however, the force makes no angle with the plane of support there should be no distortion in the plane of cleavage. There should also in all cases be a second direction of elongation perpendicular to the grain and at a considerable angle to the cleavage plane.

This theory explains at least most of the characteristics of slate, including that of steps. The second elongation just mentioned certainly exists in some cases, but I have not data enough to assert its universality. The practical difficulties of fully determining the position of the strain ellipsoid from a fossil are such that the omission of other observers to

note the existence of this elongation does not seem to me fatal to the theory. Many observers have obtained satisfactory evidence of elongation in the direction of the grain of the slate, while few, if any, of them appear to have sought for another direction of elongation not in the plane of cleavage.

The theory here advanced has the advantage of being based on some of the best-established facts of natural philosophy and of connecting cleavage in the most intimate and definite manner with schistosity, jointing, faulting, and systems of fissures. It also exhibits the cleavage of slate and the master joints, which usually intersect the cleavage planes at very large angles, as two features of a single strain.

Neither Hooke's law nor any other exterpolated generalization has been employed in reaching conclusions as to the origin of slaty structure. Poisson's hypothetical solid was assumed only in an example in order that the formulas might receive a numerical and geometrical illustration.

Summary.

The studies here presented are an outgrowth of field-work in the Sierra Nevada of California. That range is intersected by faults, joints, schistose and slaty cleavages to such an extent that, on a scale of one mile to the inch, their average separation would be for the most part microscopic. In many areas these dynamic manifestations are very systematic. Such of them as can be considered as concomitants of infinitesimal strain have been treated in a former paper. In a great proportion of cases, however, the strains have been finite. Only such areas are here considered as may be regarded as uniformly affected by finite strains.

In the first portion of the paper finite strain is considered from a purely kinematical standpoint. The subject is treated rather fully because, for the purpose in hand, it is needful to take an extended view of the possibilities. The most important topic is that of the planes of maximum tangential strain and the manner in which they range relatively to the material of a solid which is undergoing strain.

The relations of stress to strain are next sketched, the nature of a finite shear is elucidated, and Hooke's law is examined. Hooke's law is shown to differ from the statement that "stress is proportional to strain" when the deformations are finite. Viscosity, flow, plasticity, ductility and rupture are defined, and the relation of plastic solids to fluids is explained.

The conclusions reached are then applied to cases such as may arise in geology. Large masses of rocks, it is assumed, may be considered as homogeneous. Were it necessary to take into consideration the minute texture of rocks, any general conclusions as to their behavior under orogenic stress would be impracticable. Simple irrotational pressure is first taken up. It is shown that such a pressure will produce two sets of fissures crossing one another at angles approaching 90° if the rock is brittle. If it is plastic, two sets of schistose cleavages will replace the fissures. The line of force bisects the obtuse angles of the cracks or cleavages. Use is made of the theory of this case to prove in a very simple manner why mica scales and flat sand grains tend to arrange themselves parallel to the bedding of sedimentary rocks, and why flat pebbles in water-channels "shingle up stream."

A mass resting on a yielding foundation and subjected to an inclined force is briefly discussed. This case closely approaches that of the simple irrotational pressure. It seems to account for unsymmetrical schistosity.

The most interesting case is that of a mass resting upon a rigid foundation and affected by a force inclined to the foundation at any angle. It really includes the case of the simple irrotational pressure. If the mass is brittle and is strained so gradually as not to bring viscosity into play, the material will rupture in columns, the axes of which are parallel to the fixed plane of support and at right angles to the force. If the strain is so rapidly produced as to excite viscosity, only one set of fissures will form, and these will be intermediate in direction between the line of force and the projection of the force on the fixed plane. If the rock is plastic (or if it is kept strained between the elastic limit and the breaking point sufficiently long to undergo considerable deformation) the fissures intersecting the angle between the line of force and the fixed plane will be replaced to a greater or less extent by cleavage planes; and if the force does not approach the vertical to the fixed plane, these cleavage planes will preserve a nearly constant direction and have a slaty character. In this case the second set of planes of motion, if they receive expression at all, will cut sharply across the cleavage planes as master joints. This seems to be the only way in which slate-like structure can result from the action of force on homogeneous matter.

The spacing of fissures formed by inclined pressures is discussed on the hypothesis that they are so disposed as to lead to the greatest depotentialization of energy. This leads to an exceedingly simple formula for the thickness of a column in a direction perpendicular to either pair of bounding planes. The formation of a single system of parallel fissures

and the existence of undistributed faults are shown to arise in particular cases of the formula. This formula is applicable only when the rupture is not brought about by a very rapid strain. When the strain is impulsive it is shown that the interference of vibrations attending rupture may cause further parallel ruptures. The suggestion is made that thick slates and flags may possibly be due to plastic deformation attended by vibrations.

As jointing has been referred to tensile stress, rupture through tension is discussed. It is shown that curved or broken lines, and not plane partings, must result; and the columnar structure of lavas receives a seemingly sufficient explanation.

The last portion of the paper is occupied by a review of the theories and observations on jointing and slaty cleavage. It is maintained that joints are always attended by macroscopic or microscopic faults, and that they are closely allied to slaty cleavage. The ascription of slaty structure to the presence of deflected mica scales and flattened particles is pronounced unsatisfactory. Glass, wax and other substances in which slaty cleavage has been artificially produced can hardly owe their cleavage to such a distribution of flat particles, while sedimentary rocks in which the flat particles are mostly parallel to the bedding do not show slaty cleavage.

Analysis of certain well-known experiments and of some made for this paper shows that artificial slaty cleavage is always attended by rotational strains, such as those to which slaty cleavage is ascribed above. The theory of this paper (that slate is due to pressures inclined at small angles to the cleavage plane and standing at right angles to the grain of the slate) is shown to account for grain, " side " and " end," for elongation of fossils in the direction of the grain, contraction in the cleavage plane at right angles to the grain, and for master joints which intersect the cleavage plane along the grain and make a large angle with this plane.

The most important result of the investigation is that jointing, schistosity and slaty cleavage all imply relative movement, and are thus as truly orogenic as faults of notable throw. They may all be regarded as orogenically equivalent to distributed faults. The great number of joints and planes of slaty cleavage compensates for the minute movement on each, and the sum of their effects is probably at least as important as that of the less numerous faults of sensible throw.

In the light of this conclusion it appears that if one could reproduce the orogenic history of the Sierra in a moderate interval of time on a model made to a scale of one mile to the inch, it would seem to yield

to external and bodily forces much like a mass of lard of the same dimensions.*

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* I desire to express my thanks to Professor R. S. Woodward, of the Coast and Geodetic Survey, for his kindness in reading this paper in manuscript and for giving me the benefit of his advice. This is not the first time I have had the advantage of Professor Woodward's profound knowledge of physics and keen scientific judgment.

WASHINGTON, D. C., *July 1, 1892.*

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THE THICKNESS OF THE DEVONIAN AND SILURIAN ROCKS OF CENTRAL NEW YORK

BY CHARLES S. PROSSER

(Presented before the Society August 16, 1892)

CONTENTS

INTRODUCTION.

The discovery in commercial quantities of natural gas and oil in the Trenton limestones of Ohio and Indiana led to the drilling of numerous test-wells in other states that were underlain by this formation. The attention of prospectors was early directed to New York state as a promising field, and in the spring of 1887 a test-well was drilled in central New

York, near Morrisville, Madison county. At that time the writer, who was an instructor in the geological department of Cornell university, recognized the value of the data that might be obtained from these well records in giving the thickness and dip of the various terranes composing the series of New York rocks. During the remainder of 1887 and the years of 1888–'89, when test-wells were being drilled at numerous localities in New York, various wells were visited personally and arrangements made with the owners and drillers for securing reliable and complete sets of samples. As a result of these efforts, a large amount of data concerning the thickness of the New York geologic formations has been obtained, and two papers describing the sections along the meridians of Cayuga lake and the Genesee river have been published.*

In the present paper it is intended to describe another of these general sections crossing the state in a north-and-south line. The section selected is the one containing the record of wells drilled at Binghamton, Norwich, Morrisville, Utica, Chittenango, Tully, Syracuse, Fulton, Sandy Creek and Watertown, and as it is approximately along a line somewhat east of the 76th meridian, with one-half of its length following the Chenango river valley, it may very appropriately be designated the section of Central New York.

Records of the Wells.

Binghamton Well and Section.—The southernmost well of this series, which is first to be considered, is one drilled at Binghamton, Broome county, New York. This well is located on the farm of ex-Sheriff Brown, one-half mile south of the Susquehanna river and about ten rods from the southeastern corner of the city limits. It was reported by Mr G. M. Kepler as on the hillside about 70 feet above the city proper, which would make its elevation about 940 feet above tide.†

The geologic horizon of the mouth of the well is in the Chemung stage, but not at its summit, which is considerably higher. Vanuxem stated that "the Catskill group covers the highest grounds on the south side of the Susquehanna [river]."‡ Personal examination in this region shows that Vanuxem was inclined to make the base of the Catskill too low, and that Chemung fossils occur in what he called Lower Catskill. The general order of the faunas and formations of the Chenango valley

*The Thickness of the Devonian and Silurian Rocks of Western Central New York. Am. Geol., vol. vi, October, 1890, pp. 199–211.

The Thickness of the Devonian and Silurian Rocks of Western New York, approximately along the line of the Genesee river. Proc. Rochester Acad. Science, vol ii, May, 1892, pp. 49–104.

†The altitude of the N. Y., L. E. and W. R. R. station at Binghamton is stated by Gannett to be 868 feet (Bull. U. S. Geol. Surv., no. 76, p. 52).

‡Geol. New York, part iii, 1842, p. 296.

section from the Hamilton stage up into the Upper Catskill has been well described by Professor H. S. Williams.*

The Binghamton well was drilled during the fall of 1887 and the winter of 1888 by Mr G. M. Kepler, superintendent of the East Pennsylvania Oil and Gas company, to whom the writer is indebted for a series of specimens illustrating its geologic section, as well as to the driller, Mr C. W. Henderson, for valuable information in reference to this well.

SECTION OF WELL AT BINGHAMTON, NEW YORK.

Approximate altitude, 940 feet.

Depth. Feet.	*Thickness.*† Feet.	*Kind of rock.*	*Formation.*
50	100	Bluish gray argillaceous shale	Chemung and Portage.‡
150	100	Grayer and more arenaceous	" "
250	100	Bluish argillaceous shale	" "
350	200	Bluish finely arenaceous shale..........	" "
550	150	Grayish and blue arenaceous and argillaceous shales	" "
700	50	Grayish finely arenaceous chips, with fragments of fossils and calcite crystals.	" "
750	50	Grayish arenaceous shale	" "
800	50	Arenaceous and somewhat calcareous; some of the chips have a brownish-red tint	" "

*Proc. Am. Assoc. Adv. Sci., vol. xxxiv, 1886, Chart of "Meridional Sections of the Upper Devonian Deposits of New York, Pennsylvania and Ohio," section no. ix.

† From this well samples of the drillings were saved from each additional fifty feet of depth; consequently it does not follow that each lithologic zone has the exact thickness assigned to it in this column.

‡ In this well-record it is impossible to draw a dividing line between the Chemung and Portage stages; therefore the rocks composing them are classed together under the heading of Chemung and Portage. The Portage stage might be divided into Upper Portage, Oneonta sandstone and Lower Portage. The above division of the Portage would agree in a general way with that of Dr H. S. Williams as shown on section ix (Chenango) of his "Meridional sections of the Upper Devonian of New York, Pennsylvania and Ohio" (Proc. Am. Assoc. Adv. Sci, vol xxxiv). In discussing the "classification of the geologic deposits" the Professor wrote: "The Catskill deposits [Oneonta sandstone] of Chenango and Otsego counties are intrinsically not distinguishable from the upper stage of the Catskill, but appear at a lower position stratigraphically in the interval occupied by the 'Ithaca group' of the Cayuga section and by the middle part of the Portage group of the Genesee section" (*ibid.*, p. 234). Also, "the interval occupied in the Genesee section by the typical Portage fauna is . . . in the Chenango and Unadilla section . . . filled by a preliminary stage of the Catskill [Oneonta sandstone]" (*ibid*, p. 23?).

Professor Hall in 1885 said: "The Oneonta sandstone in Otsego and Chenango counties is succeeded directly by strata bearing fossils of Chemung age," and his correlation of the Upper Devonian was as follows:

"Catskill group.
Chemung group.
Oneonta { Portage group. / Hamilton (upper).
Hamilton group"

(Geol. Surv. N. Y., Palæontology, vol. v, pt. i, Lamellibranchiata, ii, p. 518).

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
850	50	Blue arenaceous shale	Chemung and Portage.
900	100	Arenaceous chips, which are mainly of a brownish-red color, a few gray ones	" "
1,000	200	Dark gray arenaceous shale. (The sample from 1,150 feet is similar to the upper part of the Norwich well)	" "
1,200	350	Bluish argillaceous shale	" "
1,550	400	Mainly gray to bluish arenaceous shale; some dark gray argillaceous shale	" "
1,950	50	Fine chips of brownish-gray finely arenaceous material; slight effervescence	" "
2,000	50	Light gray finely arenaceous sandstone (?)	" "
2,050	200	Bluish argillaceous shale with some arenaceous chips; streak white, non-calcareous	Place of Genesee?
2,250	50	Very fine dark blue chips, which immediately effervesce strongly in cold HCl and are evidently from a strongly calcareous stratum; possibly the Tully limestone	Tully?
2,300	50	Blackish argillaceous shale, somewhat calcareous; streak brown, like Hamilton	Hamilton?
2,350	50	Gray argillaceous shale; streak white, strongly calcareous	Hamilton.
2,400	150	Gray argillaceous slightly arenaceous shale; streak white	"
2,550	50	Grayish arenaceous sandstone and blue argillaceous shale, strongly calcareous; fragments of fossils, one *Spirifera?*	"
2,600	400	Grayish and bluish argillaceous and arenaceous shales and sandstone (?)	"
3,000	117	Gray arenaceous chips with fragments of fossils and calcite crystals	"
3,117		Dark gray arenaceous chips which are strongly calcareous. Bottom of well	"

Norwich Well and Section.—The next well-record to be considered is that of one drilled near Norwich, Chenango county, about thirty-five miles northnortheast of Binghamton. The well was drilled by Mr A. W. McQueen in 1887–'88, who kindly favored me with its record and a set of samples. Natural gas was found at various horizons down to 1,200 feet, but in such small quantities that it would burn but a few hours before being exhausted.

SECTION OF THE NORWICH WELL.

Approximate altitude, 1,000 feet.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
50	25	Dark gray or bluish-gray arenaceous shale, non-calcareous	Oneonta of Conrad.
75	50	Mostly argillaceous shale, but part of the chips are from a fossiliferous layer which contains *Spirifera mesacostalis*, Hall (?)	Portage.
125	50	Bluish gray arenaceous chips	"
175	75	Chips, very fine, and of a dull gray color, non-calcareous; "Sherburne sandstone".	"
250	200	Dark gray and greenish gray argillaceous and arenaceous shales; "fresh water and gas at 384 feet"	"
450	170	Bluish argillaceous shale, non-calcareous; probably Hamilton	Hamilton (?).
620	65	Gray shale, quite calcareous and rather arenaceous, with mica; must be Hamilton	Hamilton.
685	190	Lithology same as above, slightly calcareous, "gas pocket" of driller	"
875	585	Dark gray arenaceous shale, slightly calcareous; fossils at 1,020 feet	"
1,460	190	Bluish argillaceous shale, quite calcareous, fossils; *Chonetes scitula*, Hall (?)	"
1,650	400	Dark gray argillaceous and arenaceous shales	"
2,050	185	Very dark blue to blackish shale; streak white, non-calcareous	"
2,235	99	Very dark almost black argillaceous shale with brownish white streak, non-calcareous; Marcellus shale or black band in the Hamilton	Marcellus (?).
2,334		Black argillaceous shale, non-calcareous, brown streak; true Marcellus. Bottom of well	Marcellus.

This well begins in the Lower Portage, Oneonta group of Conrad or the *Paracyclas lirata* stage of the Hamilton fauna, as named by Dr H. S. Williams,* and terminates in the Marcellus. The Hamilton is shown to have a probable thickness of from 1,615 to 1,785 feet, which is the most important fact furnished by the record of this well.

Morrisville Well and Section.—In the spring and summer of 1887 the first test-well was drilled in central New York at Eagleville, about one mile south of Morrisville, Madison county, and twenty-five miles slightly

*See Prosser in Proc. Am. Assoc. Adv. Sci., vol. xxxvi, 1887, p. 210.

west of north of Norwich. This well begins in the lower half of the Hamilton stage at an altitude of probably more than 1,200 feet, and was drilled to a depth of 1,889 feet, terminating near the bottom of the Onondaga Salt group.

SECTION OF THE MORRISVILLE WELL.*

Approximate altitude, 1,200 (?) feet.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
340	31+	Pure argillaceous black shale with brownish-black streak	Marcellus shale.
371	93	Dark and light gray limestone, which effervesces very strongly in cold HCl.	Upper Helderberg (Corniferous) limestones. Place of Oriskany (?).
464	186	Dark gray limestone, mixed with some quartz grains, which are probably from the Oriskany sandstone above. The dark gray strongly calcareous limestone continues down to 628 feet, where a very light gray calcareous sample was obtained. At 578 feet a pocket of gas was struck which burned for a short time.............	Lower Helderberg.
650	125	†A dark gray limestone, which effervesces more slowly in cold HCl than the samples above, and leaves a large residue of argillaceous material; gas in small amount at 755 feet.........	Onondaga Salt group (?).
775	185	Mainly dark gray limestone, but alternating with light gray to drab limestone; effervescence usually moderately strong in cold HCl, leaving large residue; frequently grains of selenite.	Onondaga Salt Group.
960	58	Greenish-gray shale, which has a slight effervescence in cold HCl....... . .	" "
1,018	5	Chocolate-colored shale; slight effervescence in warm HCl...........	" "
1,023	87	Greenish shale; slight effervescence in warm HCl.........................	" "
1,110	69	Dark gray to blackish marlite, which effervesces quite readily in cold HCl.	" "

*This well was described by Prosser in Proc. Am. Assoc. Adv. Sci., vol. xxxvi, 1887, pp. 208, 209.

†The sample from 619 feet is a dark limestone, leaving a considerable argillaceous residue, with some grains of selenite (?), and bears a strong resemblance to the upper part of the Onondaga Salt group. However, the light colored, strongly calcareous sample from 628 feet makes it appear probable that it is better to consider the Onondaga Salt group as beginning at about 650 feet.

Depth. Feet.	Thickness. Feet.	Kind of rock.	Formation.
1,179	36	Bluish-gray marlite, which is quite calcareous	Onondaga Salt group.
1,215	44	Dark gray to drab impure limestone or marlite; effervesces strongly in cold HCl	" "
1,259	41	Dark gray to drab marlites mixed with crystals of salt. The driller reported 10 to 12 feet of rock-salt at 1,259 feet; also chocolate and green shales	" "
1,300	100	Chocolate and green variegated marls, with a little bluish shale	" "
1,400	60	Mostly chocolate shale, with an occasional green and blue chip	" "
1,460	105	Mostly green and bluish marls, with an occasional red chip	" "
1,565	225	Clear red shale, with an occasional green chip	" "
1,790	25	Blue argillaceous shale, slightly calcareous; small amount of salt from evaporation about the cork of the vial	" "
1,815	5	Drab gray limestone or marlite; effervesces readily in cold HCl, but leaves a large residue; salt as in sample above	" "
1,820	54	Dark blue argillaceous shale and marlite	" "
1,874	15	Dark blue limestone, which has a strong effervescence in cold HCl	" "
1,889		The last sample, from 1,889 feet, is partly limestone, but contains more blue argillaceous shale. Bottom of the well in the Onondaga Salt group*	" "

Chittenango Well and Section.—A well which has furnished an important section for the purposes of this paper was drilled during the first half of 1890, at Chittenango, Madison county. Mr F. W. Lamphere, of that village, carefully preserved a complete set of samples from this well, with an accurate record of their depths, which eventually reached me for examination. Chittenango is seventeen miles northwest of Morrisville,

* In the preliminary record of this well it was reported that possibly the Niagara was reached at 1,805 feet and the Clinton at 1,874 feet (Proc. Am. Assoc. Adv. Sci, vol. xxxvi, pp. 208–209). A comparison of the samples from this well with those of the Chittenango and other wells convinces me that the Morrisville well did not reach the Clinton stage, but probably ceased near the bottom of the Onondaga Salt group. The driller at 1,880 feet reported the Clinton iron ore and stated that "slight impressions of lenticular grains, about the size of a pin-head, oval and apparently of a concretionary nature, were seen." It is probable that some other substance must have been considered iron ore, as the samples from 1,879 feet and 1,884 feet do not indicate its presence.

and the well is located in the western part of the village, on the bank of the Chittenango creek. The Chittenango station of the New York Central and Hudson River railroad is 417 feet above tide, and, barometrically, the mouth of the well is about 27 feet higher, making the altitude approximately 444 feet above tide. Natural gas in small quantities was obtained at several horizons. A little gas was struck at a depth of 950 feet in the Medina. The largest amount occurred in the Trenton limestone at a depth of 2,651 feet, but gas was reached at 2,690, 2,875, 2,884 and 2,904 feet. At first, after being closed for thirty minutes, there was a sufficient volume of gas to produce a pressure of 25 pounds to the square inch, but by the middle of August, 1890, it had decreased to 12 pounds.

SECTION OF THE CHITTENANGO WELL.*

Approximate altitude, 444 feet above tide.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
182	24	Bluish and grayish chips mixed with reddish dirt........................	Drift (?).
206	179	Bluish marlite, which effervesces quite strongly in cold HCl..........	"
385	5	Mostly chocolate-red marlite with some greenish and a few gypsum chips....	Onondaga Salt group.
390	10	Bluish marlite with some red and green shale.......................	" "
400	34	Clear reddish-chocolate shale with just a few green chips..................	" "
434	11	Mottled chocolate and green shales....	" "
445	16	Green shale with a few reddish chips..	" "
461	54	Dark gray and bluish-gray limestone, which effervesces rather slowly at first in cold HCl, but becomes strong on standing. The samples leave a considerable residue. Occasionally some red and green chips; at 500 feet grains of salt.......................	" "
515	52	Bluish-gray and bluish-black limestone with some pinkish chips; strong effervescence in cold HCl...............	Niagara (?).
567	33	Green argillaceous shale, generally non-calcareous.........................	Clinton.
600	44	Bluish-gray shale, which is slightly calcareous and arenaceous.............	"

* The record of this well is based upon a set of specimens purchased by the United States Geological Survey and now deposited in the United States National Museum.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
644	11	Dark gray and rather pinkish chips, which effervesce strongly in cold HCl and contain hematite iron ore; some greenish, argillaceous, non-calcareous shale	Clinton "iron-ore bed."
655	225	Green argillaceous shale, non-calcareous; brachiopod shells at 800 feet	Clinton.
880	10	Greenish to greenish-gray chips, not so argillaceous and scarcely calcareous; a few reddish chips like iron ore	"
890	12	Greenish quartzitic chips mixed with green argillaceous shale; a good many white, vitreous, angular chips that are apparently quartz grains	Medina.
902	4	Mainly chocolate-red chips of sandstone (?) mixed with white quartz grains	"Gray band" (?) of Medina.
906	48	Greenish argillaceous shale and sandstone mixed with white vitreous grains of quartz	Medina.
954	456	Mainly brownish-red quartzose sandstone, with some greenish-gray sandstone and argillaceous green shale	"
1,410	107	Greenish-gray quartzose sandstone, with some bluish shale	Oswego sandstone.
1,517	640	Mainly blue argillaceous shale, with some bluish-gray arenaceous shale or sandstone	Lorraine or Hudson shale.
2,157	233	Blackish argillaceous shale; streak slightly brownish	Utica shale.
2,390	60	Blackish argillaceous shale, with brown streak, but mainly gray calcareous chips; at about the top of the Trenton limestone	" "
2,450	50	Clear sample of dark blue limestone; strong effervescence in cold HCl; undoubted Trenton	Trenton limestone.
2,500	390	Dark gray and light gray limestone, with some dark blue limestone, strongly calcareous; fossils, brachiopods (Orthis ?), at 2,600 feet; brachiopods at 2,710 feet	Trenton.
2,890	88	Moderately dark gray limestone; fair effervescence in cold HCl, but containing a large amount of non-calcareous material (argillaceous ?)	"

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
2,978	48½	Lightish gray, with some dark gray magnesian limestone; effervescence very slight in cold HCl, but becomes strong on heating....................	Trenton.
3,026½		Bottom of well.	

The well begins in the colored marls of the Onondaga Salt group, and reaches the Clinton at a depth of 567 feet. The thickness of the different stages in this well is as follows: Clinton, 323 feet; Oneida conglomerate, 12 feet; Medina sandstone, 508 feet; Oswego sandstone, 107 feet; Lorraine shales and sandstones of the Hudson series, 640 feet; Utica shale, 233 feet, and penetrates the Trenton limestone to a depth of 636½ feet.

Utica (Globe Woolen Mills) Well and Section.—A well was drilled by the Globe woolen mills to the depth of 1,720 feet in the city of Utica, near the level of the Erie canal, and the samples were kindly placed at my disposal for study by Mr Charles D. Walcott, of the United States Geological Survey. This well is about thirty-one miles east of Chittenango and twenty-five northeast of Morrisville.

SECTION OF THE GLOBE WOOLEN MILLS WELL AT UTICA, NEW YORK.

Approximate altitude, 428 feet.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
370	200	Clear, black argillaceous shale with brownish streak, slightly calcareous.................	Utica shale.
570	330	Dark blue limestone; strong effervescence in cold HCl; fragments of fossils at 650, 810 and 850 feet; fragments of brachiopods at 730, 750, 790 and 830 feet.................	Trenton limestone.
900	180	Drab to bluish-gray massive limestone, which effervesces strongly in cold HCl, and light gray, glistening limestone, which does not effervesce strongly in cold HCl...........	" "
1,080	180	Light gray powder, which is strongly calcareous; very marked effervescence in cold HCl....................................	Calciferous (?).
1,260	140	Slightly brownish-gray sample, composed largely of white vitreous quartz grains with some mica grains; non-calcareous........	Calciferous.
1,400	320	Mainly light gray samples, composed chiefly of white or vitreous quartz grains; some are of slightly brownish color, and part of the samples are quite badly iron-stained..	Potsdam (?).
1,720		Bottom of well.	

Campbell Well and Section.—Very interesting for comparison with this well is the record of the Campbell well, three miles west of Utica, which was drilled to a depth of 2,250 feet. This well was described by Mr Charles D. Walcott in August, 1887,* and through his courtesy the writer has had the pleasure of studying the set of samples saved from it. The record of this well as reported by Mr Walcott may be briefly summarized as follows:

SECTION OF THE CAMPBELL WELL NEAR UTICA, NEW YORK.

Depth. Feet.	*Thickness.* Feet.	*Formation.*
	90	Lorraine shale of the Hudson group.
90	710	Utica shale.
800	350	Trenton limestone.
1,150		Gap of 180 feet between the Trenton and Calciferous, 100 feet of which probably belongs to the Calciferous, which would make the top of the Calciferous at about 1,230 feet.
1,330	260	Calciferous and arenaceous strata, 260 feet; Calciferous in all about 360 feet in thickness.
1,590	410	Potsdam.
2,000	100 +	Pre-Cambrian and Archean.
2,100 +		

The careful study of the Campbell well record and specimens has furnished much assistance in interpreting the record of the Utica well. The top of the Trenton limestone is reached at a depth of 570 feet in the Utica well and at 800 feet in the Campbell well, a difference of 230 feet. Supposing the formations to have about the same thickness, then the top of the Calciferous might be expected at a depth of about 1,000 feet, and the light gray, strongly calcareous rock, which is considered as representing the Calciferous, occurred at 1,080 feet. In the same manner the top of the Potsdam would be reached at about 1,360 feet, while the sample which is regarded as probably coming from near the top of the Potsdam was reached at a depth of 1,400 feet, and the bottom of the well, at a depth of 1,720 feet, is still in this formation, the Archean not having been reached.

The line of separation between the Trenton limestone and the Calciferous is somewhat difficult to determine, and it is especially so between the Calciferous and Potsdam. The point at 1,400 feet, indicated as the beginning of the Potsdam, can only be taken as probably near the line of separation between these two formations.

Syracuse (State) Well and Section.—In 1884 the "state well" was drilled at the southern end of Onondaga lake, near Syracuse, about fifteen miles

*Proc. Am. Assoc. Adv. Sci., vol. xxxvi, pp. 211, 212.

west of Chittenango. The altitude of Onondaga lake is given at 361 feet,* so that the altitude of the mouth of the well may be called approximately 365 feet. This well was drilled to the depth of 1,965 feet. One hundred and seventy-five samples were saved and the record of the well was published by Dr F. E. Englehardt in 1885.†

Later Dr Englehardt kindly donated this set of samples to the United States National Museum and the writer has carefully examined the entire collection.

SECTION OF THE STATE WELL NEAR SYRACUSE, NEW YORK.

Approximate altitude, 365 feet.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
430	25	Reddish, grayish, white and brownish-red quartz grains, with pebbly material.	Drift.
455	100	Chocolate-colored marl, slightly calcareous..........	Onondaga Salt group.
555	23	Green argillaceous shale or marl, slightly calcareous..........	" "
578	332	Bluish shaly limestone; dark gray, glistening limestone, which effervesces very strongly in cold HCl; drab and almost black shaly limestone.........	Niagara limestone.
910	98	Green argillaceous non-calcareous shale, with greenish-gray limestone. At 995 feet oölitic iron ore with green shale..	Clinton.
1,008	38	Grayish and brownish arenaceous chips, very slightly calcareous at 1,008 feet, which may probably be regarded as the upper part of the Medina. Below this grayish and whitish quartz grains with a little greenish, argillaceous and arenaceous shale..........	Medina.
1,046	769	Slightly brownish-red and greenish silicious sandstone at 1,046 feet. Below this white, pinkish and greenish quartz grains, some greenish shale, but chiefly brownish-red silicious sandstone; also some greenish-gray silicious sandstone..........	Medina, 807 feet thick.
1,815	150	Greenish-gray silicious sandstone and shale, with some blue argillaceous shale.	Oswego sandstone.
1,965 ‡		Bottom of well..........	" "

* Geological map of Onondaga county, in Ann. Rep. Supt. Onondaga Salt Springs for 1884.

† Ibid., pp. 15–17.

‡ The depth of sample 175 is marked as 1,965 feet, but Dr Englehardt gives the depth of the well as 1,969 feet. (Ibid., p. 17.)

The above interpretation agrees very closely with the correlation of the section which was made by Dr Englehardt. The Doctor gives the top of the Niagara limestone as at 578 feet, which is the same as for my section. The top of the Clinton, which is at 910 feet, is not stated, but of course the iron-ore stratum was noticed and correctly placed in the geologic series. At 1,008 feet are grayish and brownish arenaceous chips, which the writer is inclined to refer to the Medina, although Dr Englehardt considered a "red-brown sandstone" at 1 075 feet as the top of the Medina. Finally, at 1,815 feet is the top of the Oswego sandstone, in which formation is the bottom of the well.*

Greenpoint (Gale) Well and Section.—The "Gale" well at Greenpoint, on the eastern shore of Onondaga lake, about four miles north of Syracuse, was drilled in 1884 to the depth of 1,600 feet. This well section was also described by Dr Englehardt,† and the specimens donated to the United States National Museum. The writer has examined the set of samples, and would give the section as follows:

SECTION OF THE GALE WELL NEAR SYRACUSE, NEW YORK.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
65	457	Chocolate-red, green, blue and dark gray shales and marls........................	Onondaga Salt group.
522 ‡	320	In the upper part blue calcareous shales or shaly limestone, and below very dark gray to blackish, glistening limestone; some of the samples dark blue, part with strong effervescence in cold HCl, and the remainder with slight effervescence, which is increased on heating; the lower part is largely blue shaly limestone; fragments of brachiopods and lamellibranchs at 700 feet....	Niagara (?)
842	149	Mainly clear, green argillaceous shale; at 970 feet some iron ore, more at 971 feet, and sample from 976 feet largely composed of oölitic iron ore; at 986 feet dark gray shales with some slightly reddish chips.	Clinton.

*Compare Dr Englehardt's section in ibid., pp. 5-17, and especially the general account of the well following the section on page 17.

† Ibid., pp. 12-15.

‡ Dr Englehardt called the top of the Niagara limestone 527 feet, but the preceding sample from 522 feet varies but little in lithologic characters. Possibly it would be better to call 536 feet the top of the Niagara, where the first of the dark blue limestone occurs.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
991	583	Brownish-red arenaceous shale and silicious sandstone, alternating with dark gray, bluish-gray sandstone and olive and greenish shale....................	Medina.
1,574 *		Bottom of well in the red Medina sandstone...	"

Dr Englehardt stated: "I cannot well establish the depth at which the Niagara group passes into the Clinton group below," * but it seems pretty certain that the green argillaceous shale at 842 feet is in the Clinton, and, further, that "the passage from the Clinton group into the underlying Medina group must be about 1,007 feet from the surface where the first quartz makes its appearance. At 1,020 feet the first sandstone had been passed through and certainly the Medina sandstone reached." †

To the writer it seems better to call the brownish-red arenaceous shale at 991 feet the top of the Medina.

On comparing the record of the State and Gale wells it will be noticed that in the State well the Niagara group has a thickness of 332 feet and in the Gale well it is 320 feet. The Clinton is 98 feet thick in the State well, while in the Gale well 149 feet of greenish shale has been referred to the Clinton. Possibly this is too great a thickness for the Clinton, and it certainly seems that there should not be so great a difference in the thickness of the formation for the two wells. The State well passed through the Medina, making a total thickness for that group of 807 feet, and stopped after passing through 150 feet of the Oswego sandstone. The Gale well passed through 583 feet of the Medina group and ceased at a depth of 1,574 feet.

Tully Well Number 2 and Section.—The Solvay Process Company of Syracuse, New York, in 1888 discovered rock-salt in Tully township, in the southern part of Onondaga county.‡ More than twenty wells have since been drilled by this company, the depth to the rock-salt ranging from 974 to 1,465 feet, which is generally between 40 and 50 feet in thickness.||

Through the kindness of Mr G. E. Francis, of the Solvay Process Company, the writer has had the satisfaction of studying a set of samples

* The last sample of the set donated to the National Museum is from 1,574 feet, but Dr Englehardt gives the total depth of this well as 1,600 feet (Ibid., p. 14).

† Ibid., p. 15.

‡ See Ann. Rep. Supt. Onondaga Salt Springs for 1889, p. 27.

|| See ibid. for 1890, pp. 23–27. A general account of this region, together with a brief description of twenty-one wells, is given in the Mineral Resources of the United States for the years 1889–'90 (Washington, 1892), pp. 486, 487.

from one of these wells. The well is the one known as No. 2 of the D group, which is about two and one-half miles northwest of Tully village, from which samples were saved from every ten feet of depth.

SECTION OF THE TULLY WELL, NUMBER 2, D GROUP.

*Approximate altitude, 815 feet above tide.**

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
30	420	Mainly blue argillaceous shale, which is slightly calcareous and some of it rather arenaceous; from 410 to 450 feet slightly blackish shale with brownish streak alternating with blue argillaceous shale	Hamilton.
450	110	Mainly very black argillaceous shale with brown streak	Marcellus.
560	260	Bluish shaly limestone; strong effervescence in cold HCl; also light and dark gray limestone; fragments of fossils..	Upper and Lower Helderberg.
820	255	† First bluish-gray, shaly limestone, which has very slight effervescence in cold HCl, then mainly dark and light gray limestones, which have a stronger effervescence in cold HCl, especially the light gray chips	Onondaga Salt group(?).
1,075	40	Rock-salt............	Onondaga Salt group.
1,115		Last sample ‡.......................	" "

Fulton Well and Section.—In the winter of 1887–'88 a test-well was drilled at Fulton, Oswego county, New York, and through the kindness of Dr George A. Edwards, of Syracuse, New York, a set of samples was furnished me for study. Fulton is about twenty-three miles north-northwest of Syracuse, and the altitude of the mouth of the well is approximately 287 feet above tide. ||

*According to Mr G. E. Francis.

† No indication of the Oriskany sandstone appears in the samples; consequently it is impossible to indicate any dividing line between the upper and lower Helderberg limestones. In the same way the dividing line between the lower Helderberg and the Onondaga Salt group is not clear; but it has been taken provisionally at the point where a bluish gray magnesian limestone appears in considerable thickness.

‡ Dr Englehardt reported that this well reached the rock-salt at a depth of 1,075 feet, and that the stratum was 43 feet in thickness (Advance sheets of Dr. Englehardt's Rept. to the Supt. Onondaga Salt Reservation for 1890, p. 8).

|| Altitude estimated by Mr Thomas D. Lewis from the number of locks on the Oswego canal between Fulton and Lake Ontario.

SECTION OF THE WELL AT FULTON, NEW YORK.

Approximate altitude, 287 feet.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
42	358	Brownish-red quartz grains and chips of brownish-red sandstone; at 215 feet a few chips of greenish sandstone........	Medina.
400	185	Greenish-gray sandstone, composed largely of quartz grains, with some greenish to olive argillaceous shale	Oswego sandstone.
585	695	Mainly blue argillaceous shale, with some arenaceous shale and a little quartzose sandstone; arenaceous chips containing fragments of fossils at 875 feet..........	Lorraine shale of the Hudson group.
1,280	120	Black shale with brownish streak........	Utica shale.
1,400	335	Mainly bluish-gray limestone, which effervesces strongly in cold HCl; some dark blue and light gray limestone; fragments of fossils at 1,638, 1,665 and 1,735 feet...	Trenton limestone.
1,735 *		Last sample	" "

This well was first described by Mr Charles A. Ashburner in 1888, who reported that the well had been drilled to the depth of 1,727 feet, and gave the following section:

"Medina sandstone..................................	400	feet.
Hudson River shale..............................	880	"
Utica shale and slate............................	120	"
Trenton limestone................................	327	"
Total..	1,727	"

"At 1,727 feet, 327 below the top of the Trenton limestone, gas was struck in such force as to throw sand from the well to the top of the derrick, a height of 74 feet 10 inches. The gas caught on fire and the derrick was burned down." †

In April, 1890, Mr Charles D. Walcott published the same record, with the additional 323 feet to which the well had been drilled, making its total depth 2,050 feet. ‡

Sandy Creek Well Number 4 and Section.—Several wells have been drilled near Sandy Creek and Lacona, Oswego county, New York, for natural gas, which was obtained in moderate quantities. Mr Gilbert N. Harding, of Lacona, saved and forwarded to me a set of samples from well No. 4 of the Sandy Creek Oil and Gas Company, limited. Lacona is

* This is the depth from which the last sample came in the set furnished me for study. Mr Walcott reported that the well was drilled 315 feet deeper, reaching a depth of 2,050 feet, and that it passed through 650 feet of Trenton limestone (Bull. Geol. Soc. Am., vol. i, p. 349).

† Trans. Am. Inst. Min. Eng., vol. xvi, p. 958.

‡ Bull. Geol. Soc. Am., vol. i, p. 349.

forty miles north-northwest of Chittenango or twenty-eight miles north-east of Fulton.

SECTION OF WELL NUMBER 4, AT SANDY CREEK, NEW YORK.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
50	350	Mainly blue argillaceous shale, but with some bluish to dark gray, fine-grained sandstone, which contains fine grains of mica; segments of crinoid stems at 200 feet..........	Lorraine shale of the Hudson group.
400	145	Blackish argillaceous shale with moderately brownish streak.................	Utica shale.
545	600	Dark blue, dark and light gray limestone chips, most of which effervesce very strongly in cold HCl; fragments of fossils at 600 and 700 feet; fragments of brachiopods at 675, 750, 880, 900, 950 and 1,050 feet, and numerous fragments of well preserved brachiopods at 765, 800, 830 and 850 feet; gas at 675, 765 and 790 feet. Samples from 545, 830, 880 and 1,030 feet were blown out by gas.......	Trenton limestone.
1,145		Bottom of well in the Trenton limestone.	

Watertown Well and Section.—At Watertown, Jefferson county, 24 miles north-northeast of Lacona, a well was drilled to the depth of 530 feet by the Black River Gas and Fuel Company. A little gas was found at the depth of 253 feet, according to the driller, Mr Albrant, to whom the writer is indebted for the samples from this well.

SECTION OF WELL AT WATERTOWN, NEW YORK.

Depth. Feet.	*Thickness.* Feet.	*Kind of rock.*	*Formation.*
92	8	Light greenish, very compact, fine-grained limestone, which effervesces strongly in cold HCl...	Trenton.
100	26	Light gray limestone, strongly calcareous.........	"
126	135	Mainly light green limestone, which does not effervesce strongly in cold HCl at first, but increases on standing	"
261	14	Very light gray fine-grained limestone; effervesces strongly in cold HCl	"
275	255	Many pinkish white chips, which are usually non-calcareous; also dark green and dark gray, the gray being somewhat calcareous; near the bottom are some vitreous white quartz grains......	Calciferous?
530		Bottom of well................................	"

General geologic Section of central New York.

Composite Section.—From the preceding well-sections a general section has been compiled, giving the approximate thickness of the different formations, together with the total thickness from the Chemung, as exposed at Binghamton, New York, down to the Archean.

Well.	*Depth.* Feet.	*Thickness.* Feet.	*Formation.*	
Binghamton.	0	2,250	Mouth of the Binghamton well in the Chemung. From 900 to 1,000 feet brownish-red arenaceous chips, probably the horizon of the "Oneonta sandstone." At 1,850 feet, about the mouth of the Norwich well and lower, the "Sherburne sandstone." Place of the Genesee shale and the Tully limestone.	Chemung in part and Portage.
Norwich.....	2,250	1,785	Hamilton.	
	4,035	100 (?)	Marcellus shale.	
Morrisville ..	4,135	93	Upper Helderberg (Corniferous limestone).	
	4,228	.... (?)	Place of Oriskany sandstone.	
	....	186 (?)	Lower Helderberg.	
	4,414	1,239 +	Onondaga Salt group.	
	5,653 +	52 (?)	Niagara.	
Chittenango.	5,705	323	Clinton.	
	6,028	520	Medina.	
	6,548	107	Oswego sandstone.	
	6,655	640	Lorraine shale of the Hudson group.	
	7,295	233	Utica shale.	
	7,528	637 +	Trenton.	
Utica	8,165 +	320 (?)	Calciferous.	
	8,485	410 (?)	Potsdam.	
	8,895	....	Pre-Cambrian and Archean.	

Review of Data used.—It will be interesting to compare the thickness of these formations with that obtained for them in wells more remote from the meridian of this section.

The combined thickness of the Chemung and Portage groups was shown by the Bird Creek well, eight miles southwest of Elmira, to be considerably more than 2,700 feet for that region,* while in the Ithaca well the Hamilton is 1,142 feet thick; the Marcellus shale, 82 feet; the Upper Helderberg (Corniferous limestone), 78 feet; Oriskany sandstone, 13 feet; Lower Helderberg, approximately 115 feet, and the bottom of the well is in the Onondaga Salt group after passing through 1,285 feet of limestone, shale and salt belonging in that group. The Seneca Falls

* Prosser: Am. Geol., vol. vi, p. 201.

well began in the upper part of this formation and passed through 950 feet before reaching the Niagara limestone.*

As near as can be determined, the Niagara limestone has a thickness of 52 feet in the Chittenango well, while in the State well near Syracuse it is 332 feet thick; in the Gale well, 320 feet, and in the Clyde well, 335 feet.† However, it is often very difficult to decide on the dividing line between the lower gray marls and limestones of the Onondaga Salt group and the beginning of the Niagara limestone; hence there is some doubt as to the accuracy of the thickness of this formation.

The Clinton group has a thickness of 323 feet in the Chittenango well; in the State well 98 feet, and the Gale well of 149 feet. There is apparently too great a difference in the thickness of this formation as given in the State and Gale wells when their proximity is considered, but the samples as labeled seem to furnish the above result. The Clinton is approximately 83 feet in thickness in the Clyde well, and in the Seneca Falls well the Niagara and Clinton groups have a thickness of 400 feet.‡

The Medina is 508 feet thick in the Chittenango well and 807 feet in the State well. The Gale well penetrated the Medina 583 feet; in the Clyde well it is 942 feet thick, and in the Wolcott well 690 feet.‖ The Oswego sandstone is 107 feet thick in the Chittenango well; 185 feet in the Fulton, and in the Wolcott 210 feet. The Clyde well stopped after passing through 92 feet § of it and the State well penetrated it to a depth of 150 feet.

The Lorraine shale of the Hudson group is 640 feet in thickness in the Chittenango well and 695 feet in the Fulton well. The Sandy Creek well began in the Lorraine, passing through 400 feet before reaching the Utica shale. In the Wolcott well there is 820 feet of shales and sandstone which may be referred to the Lorraine and the Utica shale.¶

The Utica shale which forms the surface rock at Utica was shown by the Globe Woolen Mills well to have a thickness of at least 570 feet in that city. Mr Walcott reported its total thickness to be 710 feet in the Campbell well, three miles west of Utica.** This shale is 233 feet thick in the Chittenango well; 120 feet in the Fulton, and 145 feet at Sandy creek. The Trenton limestone in the Utica well has apparently a thickness of 510 feet, but on account of the great difficulty in deciding upon what shall be considered the top of the Calciferous this statement must be accepted as partly an estimate. Mr Walcott in a similar manner concluded that the Trenton had a thickness of about 430 feet in the Campbell well.†† The Chittenango well penetrated this formation to a depth of 637 feet, and in the same way the Sandy Creek well passed through

* Ibid., pp. 202–203.
† Ibid., p. 204.
‡ Ibid., pp. 203, 204.
‖ Ibid., p. 204.
§ Ibid., p. 204.
¶ Ibid., p. 204.
** Proc. Am. Assoc. Adv. Sci., vol. xxxvi, p. 212.
†† Ibid., p. 212.

600 feet of Trenton; the Fulton well, 650 feet, and the Wolcott well, 750 feet.*

A GENERALIZED GEOLOGIC SECTION ALONG THE MERIDIAN OF THE CHENANGO RIVER FROM THE TOP OF THE CHEMUNG DOWN TO THE ARCHEAN.

In order to show the variations in the above section as compared with our previous knowledge of the thickness of these terranes, a general geologic section ranging through the same series of formations has been compiled from books and geological articles. In this compilation the maximum thickness of the terranes, as near the line of section as possible, has been taken. The notes following the section give the authorities and references.

Depth. Feet.	*Thickness.* Feet.	*Authority.*	*Formation.*
0	2,000	A	Chemung and Portage.
2,000	20	B	Genesee.
2,020	25	C	Tully.
2,045	1,100	D	Hamilton.
3,145	100	E	Marcellus.
3,245	70	F	Upper Helderberg (Corniferous).
3,315	20	G	Oriskany.
3,335	120	H	Lower Helderberg.
3,455	700	I	Onondaga Salt group.
4,155	50 (?)	J	Niagara.
4,205	200	K	Clinton.
4,405	400	L	Medina.
4,805	100	M	Oswego sandstone or Oneida conglomerate.
4,905	600	N	Lorraine shale of the Hudson.
5,505	180	O	Utica.
5,685	330	P	Trenton.
6,015	350	Q	Calciferous.
6,365	410 (?)	R	Potsdam.
6,775			Archean.

REVIEW OF AUTHORITIES.

Authority and reference for the thickness of the terranes, as given in the preceding section.

A.—Dr H. S. Williams estimated the thickness of the rocks from the base of the true Catskill down to the horizon of the Genesee shale or the top of the Hamilton, for the Chenango valley, as approximately 2,000 feet (Proc. Am. Assoc. Adv. Sci., vol, xxxiv, 1886, Chart on the "Meridional Sections of the Upper Devonian Deposits of New York, Pennsyl-

* Am. Geol., vol. vi, p. 204.

vania and Ohio," section no. ix). On a section crossing the Catskill range from Schenevus to Glasco, prepared by Professor James Hall, it was shown that the "Portage and Chemung have a thickness of more than 2,000 feet" for that region (ibid., vol. xxiv, B, 1876, p. 82).

B.—Prosser noted: "Black argillaceous shales 20 feet in thickness near Smyrna [in the Chenango valley, in the northern part of Chenango county"] (ibid., vol. xxxvi, 1887, p. 210).

C.—Prosser reported: "Limestone layers, separated by calcareous shales, with a total thickness of 25 feet . . . near Upperville, in Smyrna township." At least part of this series belongs to the Tully limestone (ibid., p. 210). Emmons said: "In Albany and Schoharie counties it [Tully limestone] is unknown. . . . The thickness . . . is from 12 to 15 feet" (Agriculture of N. Y., vol. i, 1846, p. 186).

D.—Professor Hall wrote: "The thickness of this group [Hamilton] on the eastern limit of the district [fourth geological district, Cayuga lake region] cannot be less than 1,000 feet" (Geol. N. Y., pt. iv, 1843, p. 194). Vanuxem said: "The group is of great thickness; in no part probably less than 300, and swelling to 700 feet" (Geol. N. Y., pt. iii, 1842, p. 151). Professor Dana stated that "the greatest thickness—about 1,200 feet—is found east of the center of the state" (Manual Geology, 3d ed., p. 266); but it is also stated that "the Hamilton strata are 1,000 feet thick in central New York" (ibid., p. 267). While Professor Hall said, "The thickness of this group [Hamilton] along the Schoharie creek is much greater than has been supposed, amounting probably to 3,500 feet" (Proc. Albany Institute, vol. 1, 1871, p. 133). 1,100 feet seems to be a fair average for this section, based upon Hall's estimate for Cayuga lake and Dana's for eastern central New York. Emmons stated: "By estimating the fossiliferous and non-fossiliferous parts by themselves and summing up the result, we obtain from 1,000 to 1,200 feet thickness. In Albany and Schoharie counties the thickness appears to be much greater than in the western counties" (Agri. of N. Y., p. 185).

E.—Vanuxem wrote: "Near Marcellus and in other parts of Onondaga where best observed they show no fossils for one or two hundred or more feet where thickest" (Geol. N. Y., pt. iii, p. 147); also, "A boring of 100 feet for coal was made in the Marcellus shales by Mr Sage near the road from Chittenango to Cazenovia" [Madison county] (ibid., p. 149); and Dana states that "The Marcellus shale rarely exceeds in thickness 50 feet" (Manual Geol., 3d. ed., p. 267). Emmons stated: "It is probably less than 100 feet at Schoharie and Manlius" (Agri. of N. Y., p. 183).

F.—Vanuxem said: "The Corniferous limestone is at its maximum thickness in the village of Cherry Valley [Otsego county], where it is probably from 60 to 80 feet thick" (Geol. N. Y., pt. iii, p. 141); while

he stated that the thickness of the Onondaga limestone "rarely exceeds 10 or 14 feet" (ibid., p. 132), and at Vannep's, near Perryville, Madison county, he gave the thickness as "about 10 feet" (ibid., p. 135). Dana wrote: "In New York the thickness of the limestone seldom exceeds 20 feet for the Onondaga and 50 feet for the Corniferous" (Manual Geol., p. 256). Emmons reported 100 feet of Onondaga and Corniferous limestone at Cherry Valley, in Otsego county (Agri. N. Y., table on p. 178; also see statement on p. 175). From the above statements it appears to be a fair estimate to call the Corniferous limestone of our section 60 feet thick and the Onondaga limestone 10 feet.

G.—Vanuxem said: "At Oriskany Falls [southwestern corner of Oneida county], to the north of the village the sandstone is exposed for some distance, forming a ledge or mass about 20 feet thick" (Geol. N. Y., pt. iii, p. 125); while "the greatest thickness in the district is on the old Seneca road between Elbridge and Skaneateles [in the western part of Onondaga county], appearing to be about 30 feet thick" (ibid., p. 283, and see p. 126). Emmons reported: "At Oriskany Falls, 20 feet; at Perryville and below Cazenovia, only a few inches" (Agri. N. Y., p. 170).

H.—Professor S. G. Williams stated: "The exposure of lower Helderberg rocks at Oriskany Falls, 18 miles south of Utica, is interesting, partly because it is so laid open by deep and extensive quarries as to give nearly a complete section of about 120 feet of rocks, 115 feet of which can be definitely measured from the Oriskany sandstone, here 10 feet thick, down to the bank of the abandoned Chenango canal" (Am. Jour. Sci., 3d ser., vol. xxxi, p. 142). Emmons reported 121½ feet at Cherry Valley, Otsego county (Agri. N. Y., table on p. 178).

I.—Vanuxem, in 1840, reported "a thickness in Onondaga county of about 700 feet" (4th Ann. Rep. Third Geol. Dist. N. Y., p. 375); while in his final report he stated that the "thickness gradually increases toward the west [from the Hudson river], and reaches its maximum in the counties of Onondaga and Cayuga, where it is not less than 700 feet" (Geol. N. Y., pt. iii, p. 96); also, the red shale of this group is said to have great thickness in Onondaga county, "being more than 500 feet thick at Salina, which the deep boring of 1839 made known" (Vanuxem, 5th Ann. Rep. Third Geol. Dist. N. Y., 1841, p. 147). This was also restated in the final report (see Geol. N. Y., pt. iii, pp. 278, 279). Professor Hall reported that on a line from Seneca or Ontario to Oswego county it is "more than 1,000 feet in thickness" (27th Ann. Rep. N. Y. State Mus. Nat. Hist., 1875, p. 128, and Proc. Am. Assoc. Adv. Sci., vol. xxii, 1874, B, p. 332); while Dana says: "They [the Onondaga Salt group beds] are 700 to 1,000 feet thick in Onondaga and Cayuga counties and only a few feet on the Hudson" (Manual Geol., p. 233). Emmons re-

ported 700 feet of red shale in Madison county and 100 feet of green shale at Cherry Valley (Agri. N. Y., table on p. 178).

J.—Vanuxem stated: "It [the Niagara] thins out to the east, leaving not a trace to be seen east of a line passing south through the village of Mohawk, in Herkimer county" (Geol. N. Y., pt. iii, p. 90); while Professor Hall wrote: "Starting from the typical locality of the Niagara group, where, of the shale and limestone, we have a thickness of something more than 200 feet, and tracing the outcrop in an easterly direction, we find a very gradual but pretty constant thinning of the beds of the formation, so that at a point 100 miles east of the Niagara river it has a thickness of scarcely 100 feet. Farther eastward, in Oneida county, the formation is still thinner" (27th Ann. Rep. N. Y. State Mus. Nat. Hist., 1875, p. 123; also Proc. Am. Assoc. Adv. Sci., 1874, vol. xxii, B, p. 327). Vanuxem, in 1840, stated that "the greatest thickness of this group [the Protean, divided later into Niagara and Clinton] must be over 200 feet" (4th Ann. Rep. Third Geol. Dist. N. Y., p. 375). Emmons stated: "On Swift creek, in Oneida county, it is a dark concretionary mass, about four or five feet thick, accompanied with a dark-colored slate" (Agri. N. Y., p. 151).

K.—Vanuxem was able to measure part of this group on Swift creek, a tributary of Sauquoit creek, in the southwestern part of Oneida county, where beds to the thickness of 94 feet are exposed, but he states distinctly that this is not the entire thickness of the group (Geol. N. Y., pt. iii, pp. 84, 85); while Dana states: "In Oneida, Herkimer and Montgomery counties the rock is 100 to 200 feet thick. . . . Near Canajoharie, which is not far from its eastern limit, the formation has a thickness of 50 feet" (Manual Geol., p. 220). Emmons stated: "It is between 50 and 60 feet in Warren, in Herkimer county" (Agri. N. Y., p. 150).

L.—The Medina in the State well, near Syracuse, has a thickness of about 807 feet (see Englehardt, Ann. Rept. Supt. Onondaga Salt Springs for 1884, pp. 16, 17); while Professor Hall wrote: "This rock [Medina] thins out entirely in an easterly direction in Oneida county, showing from that point westerly as far as Lake Ontario a gradual increase in thickness" (Geol. N. Y., pt. iv, 1843, p. 43). Since the line of the present section is about half way between Syracuse and the eastern side of Oneida county, it would seem from the above statements that 400 feet would be about the thickness of the Medina for this section.

M.—On the northern branch of Salmon river, which is very nearly in line with the present section, Vanuxem stated: "Not less than about 100 feet of the rock [Oswego sandstone] is there exhibited" (Geol. N. Y., pt. iii, p. 70). Emmons stated: "The whole thickness of the sandstone and limestone is not over 100 feet" (Geol. N. Y., pt. ii, p. 126). Professor Emmons also reported the Oneida conglomerate at Utica as "a mass 20 or 30 feet thick overlying and resting immediately upon the thin-bedded

Lorraine shales" (Agri. N. Y., pp. 125, 126). Vanuxem reported the Oneida conglomerate in Herkimer to be "from 15 to 25 feet thick;" while in a gulley southeast of Utica "it appears to present its maximum thickness of about 35 feet" (Geol. N. Y., pt. iii, p. 76). Dana stated the thickness of the Oneida conglomerate to be "100 to 120 feet in Oneida county, New York" (Manual Geol., p. 218), and, further, "the Oneida conglomerate is the surface rock in Oneida and Oswego counties, New York. It is here 20 to 120 feet thick, but thins out to the eastward in Herkimer county" (ibid., p. 220). He evidently used the terms Oneida conglomerate and Oswego sandstone as synonymous, and gave the thickness of the Oswego sandstone for that of the Oneida conglomerate.

N.—Above the Utica shale, on the south branch of Sandy creek, Jefferson county, New York, a locality not far west of the line of this section, Mr Walcott measured 600 feet of shales and sandstones belonging to the Lorraine stage (Bull. Geol. Soc. Am., vol. 1, April, 1890, pp. 348, 349). On the "diagram" for the Lorraine section Mr Walcott gave 180 feet as Utica, then 100 feet of shale and calcareous sandstone, with 720 feet of the Lorraine above (ibid., p. 350). Furthermore, Mr Walcott has stated: "The data obtained in the study of the strata of the Hudson terrane enables me to state that that terrane has a thickness of over 6,000 feet in the valley of the Hudson" (Ninth Ann. Rep. U. S. Geol. Surv., pp. 116, 117). Vanuxem wrote: "In Schoharie county the Hudson group is undisturbed and unaltered, and its maximum thickness is not less than 700 feet" (Geol. N. Y., pt. iii, p. 61). Mather concluded: "In the valleys of Norman's kill, the Mohawk river and the Schoharie kill, they [Hudson] are beautifully exposed to view. . . . No actual measurements of these strata have been made, but it is estimated that they have a thickness of from 500 to 800 feet" (Geol. N. Y., pt. i, 1843, p. 369). Ashburner described the Knowersville well, in Guilderland township, Albany county, seventeen miles from Albany, which began 595 feet below the top of the Hudson and reached the Trenton at a depth of 2,880 feet. Consequently the Hudson group and Utica shale, if the latter be represented in this well, have a combined thickness of 3,475 feet (Trans. Am. Inst. Min. Eng., vol. xvi, pp. 951, 952). Professor Hall gave it as from 800 to 1,000 feet thick in central and northwestern New York (Geol. Surv. N. Y., Paleontology, vol. iii, pt. i, text, p. 20, foot note). Professor Emmons reported the entire thickness of the Lorraine shales at the northern termination of the Helderberg range as "not less than 700 feet" (Agri. N. Y., p. 125).

O.—Mr Walcott measured 180 feet of "dark bituminous shale in bands, alternating with a smoother lead-colored shale," along the south branch of Sandy creek, Jefferson county, New York, which was "characterized by the fauna of the Utica shale" (Bull. Geol. Soc. Am., vol. i, p. 348).

Emmons stated: "The Utica slate, in the gorges of Lorraine and Rodman [in the southern part of Jefferson county], is about 75 feet thick; it is, at least, less than 100 feet" (Geol. N. Y., pt. ii, p. 118); and also he said: "I am satisfied that its thickness never exceeds 75 feet" (ibid., p. 400). Vanuxem considered its thickness and reported it as "often showing a thickness whose maximum is about 250 feet" (Geol. N. Y., pt. iii, p. 56). Dana said: "The Utica shale is 15 to 35 feet thick at Glenn's Falls, in New York, 250 feet in Montgomery county, 300 feet in Lewis county" (Manual Geol., p. 196). Finally, Mr Walcott stated: "At the typical locality in the vicinity of Utica the formation has a thickness of over 600 feet" (Trans. Albany Inst., vol. x, 1879, p. 1). This statement was repeated in 1888 when the Campbell well was described, in the record of which 710 feet was referred to the Utica shale (Proc. Am. Assoc. Adv. Sci., vol. xxxvi, p. 212). Walcott stated in 1890 that "at Utica the Utica shale is 710 feet in thickness" (Bull. Geol. Soc. Am., vol. i, p. 347).

P.—Mr Walcott reported that in the Campbell well, west of Utica, there was probably 330 feet of Trenton limestone, and in the vicinity surface outcrops 290 feet in thickness (Proc. Am. Assoc. Adv. Sci., vol. xxxvi, p. 212). Vanuxem stated that the Trenton limestone at Copenhagen, Lewis county, "must be 300 feet thick, showing a great increase in its progress from the Mohawk river, where in no place is it 30 feet in thickness" (Fourth Ann. Rept. Third Geol. Dist. N. Y., pp. 364, 365); also, "on the Mohawk its thickness rarely exceeds 30 feet, but it increases through Oneida and Lewis, being 300 feet in the north part of the latter county" (ibid., p. 371). In his final report this statement is repeated as follows: "The greatest thickness of the Trenton limestone is in Lewis county, toward the northern end, where it cannot be less than 300 feet. It diminishes in thickness going east and south, rarely exceeding 30 feet in any part of the Mohawk valley. It is not so thick at the east as at the west end" (Geol. N. Y., pt. iii, p. 49; also, see similar statement on p. 268). Emmons said: "The greatest thickness which I have been able to give to the Trenton limestone is 400 feet. At Chazy, where it is made up of alternating beds of limestone and shale, this, according to the best estimate I can make, is the thickness of this rock. The gray variety is, however, wholly wanting at this locality; if that is to be considered as a distinct mass, the whole thickness may be greater than I have given it; but at Watertown, where both varieties exist, the thickness cannot much exceed the above estimate. At Glen's Falls it is much less" (Geol. N. Y., pt. ii, p. 116); also, "the thickness of the Trenton limestone at Watertown, including the whole mass, which extends south, and which is embraced in the section, is about 300 feet" (ibid., p. 388). The Black River limestone "is about 10 feet thick

Chart showing the estimated and actual Thickness of the New York Paleozoic Rocks for different Sections of the State.

Stages.	Western New York.*		Western-Central New York.†		Central New York.‡		Eastern New York.§
	Estimated thickness.	Actual thickness.	Estimated thickness.	Actual thickness.	Estimated thickness.	Actual thickness.	Measured thickness.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Pocono, white Catskill	....	....	From Barclay lower coal to top of the Chemung, 1,000.	....	....	....	1,000
Catskill, red sandstone	....	....		....	....	....	2,900
Upper Devonian, Olean conglomerate to Wolf creek conglomerate	300	Estimated 300					
Chemung	1,500 (?)	1,150+	1,200	....	2,000	2,250+	1,130
Portage	1,000	900	1,300	1,780			1,315
Genesee	90	100	100	100	20	....	Genesee and Hamilton, 1,075
Tully	....	Wanting	20	30	25		
Hamilton	400	750	1,000	1,142	1,100	1,785	....
Marcellus	50	50	50	82	100	100 (?)	900
Upper Helderberg	90	150	100	78	70	93	851 Cauda Galli, 40
Oriskany	....	Wanting	5	13	20	....	10

Lower Helderberg	....	Wanting	110	115	120	186	200
Onondaga Salt group	600	600	1,000	1,418	700	1,239	Wanting
Niagara	180	250+	140	335 (?)	50 (?)	52	do.
Clinton	80		80	83	200	323	do.
Medina	700	1,075	600	942	400	520	do.
Oswego sandstone or Oneida conglomerate	....	83	....	210	100	107	do.
Lorraine shale of the Hudson	1,030 (?)	598	1,000	820	600	640	3,500
Utica			300		180	233	....
Trenton	750	954	750	842	330	637+	500
Calciferous	40	137	80	150 (?)	350	320 (?)	....
Potsdam		....	....	....	410 (?)	410 (?)	....
Archean	....	....	....	....	....	....	....

* The Western New York section is approximately along the line of the Genesee river. See Proc. Rochester Acad. Sci., vol. ii, pp. 93–95.

† The Western-Central section is approximately along a line somewhat east of the 77th meridian and following Cayuga lake. See Am. Geol., vol. vi, pp. 205–207.

‡ The Central New York section is the one reported in the present paper, approximately along the line of the Chenango river.

§ The Eastern New York section is a general section prepared by Mr Ashburner from the top of the Catskill mountains down to the bottom of the Mohawk valley. See Trans. Am. Inst. Min. Eng., vol. xvi, p. 954; also, see the condensed statement of this paper in Mineral Resources of the United States for 1887 (Washington, 1888), pp. 474–477.

at Fort Plain" (Vanuxem: Geol. N. Y., pt. iii, p. 40). The Birdseye limestone "is about 30 feet [thick], but, like other limestones in this group, it thins out remarkably toward the south" (Emmons: Geol. N. Y., pt. ii, p. 110; also, see p. 385).

Q.—Mr Walcott reported surface outcrops of Calciferous 350 feet in thickness for comparison with the Campbell well west of Utica, in which it possibly has a thickness of 360 feet (Proc. Am. Assoc. Adv. Sci., vol. xxxvi, p. 212). Emmons wrote: "The entire thickness of the Calciferous sandrock is between 250 and 300 feet" (Geol. N. Y., pt. ii, p. 106).

R.—Mr Walcott reported Potsdam (?) sandstone 410 feet in thickness in the Campbell well west of Utica (Proc. Am. Assoc. Adv. Sci., vol. xxxvi, p. 212). Emmons stated that on the northern or Canadian slope it "is about 300 feet thick" (Geol. N. Y., pt. ii, p. 103). Mr T. B. Brooks reported in St. Lawrence county Potsdam and pre-Potsdam at the maximum 700 feet thick, part of which must be before the typical Potsdam (Am. Jour. Sci., 3d ser., vol. iv, p. 22).

Vanuxem in 1839 stated that the thickness of the whole series, from the gneiss at Little Falls to the top of the Corniferous, "taking the measure of each rock and group where its thickness is greatest, exceeds 2,000 feet" (Third Ann. Rept. Third Geol. Dist. N. Y., pp. 276). The estimated thickness of this same series as compiled from various authorities is 3,530 feet, while the actual thickness as obtained from the well sections is 4,760 feet. In addition, Vanuxem stated: "There [then] remains from 12 to 1,500 feet before completing the whole of the series of the third district; all which are anterior in origin to the coal" (ibid., p. 276). This would make a total thickness of only 3,500 feet for the entire series, while our compiled section gives 6,775 feet from the top of the Chemung to the Archean, and the actual thickness of the rocks from the Chemung, at Binghamton, which is something like 1,500 feet below the top of Vanuxem's series,* to the Archean is approximately 8,895 feet.

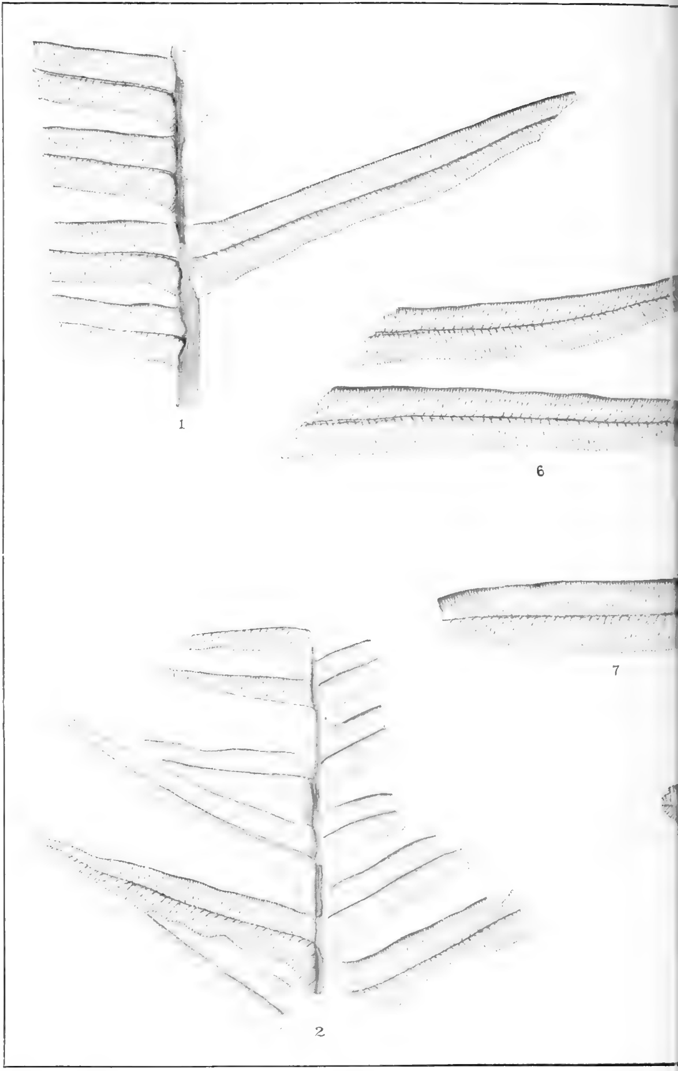
Comparative Sections of eastern, central and western New York.

For the purpose of comparison it has been thought advisable to prepare a chart (page 116) giving the thickness of the different geological formations for four sections, crossing New York in a line from north to south.

The author is responsible for the sections denominated "western," "western-central" and "central New York," but the section for "eastern New York" was measured and prepared by Charles A. Ashburner.

* Compare the Chenango section (ix) in Professor Williams' "Meridional Sections of the Upper Devonian Deposits of New York, Pennsylvania and Ohio" (Proc. Am. Assoc. Adv. Sci., vol. xxxiv).

TOPEKA, KANSAS, *December, 1892.*



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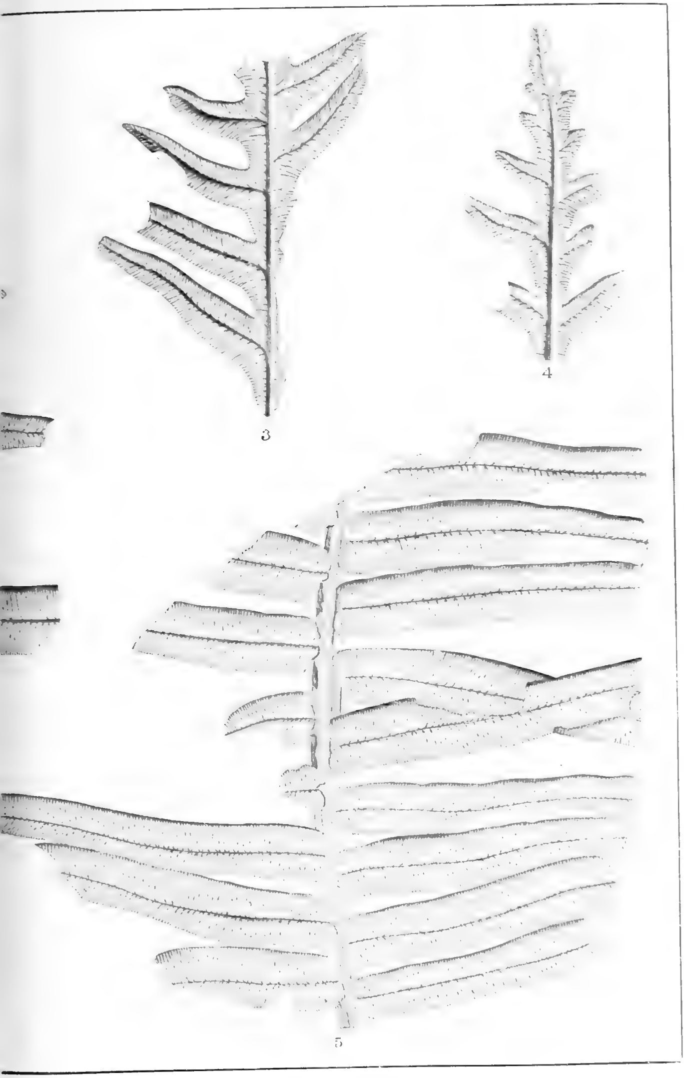

ERO'D FERN

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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A NEW TÆNIOPTEROID FERN AND ITS ALLIES

BY DAVID WHITE

(Read before the Society August 16, 1892)

CONTENTS

Introduction.—Among several collections of fossil plants from the Lower Coal Measures of the Carboniferous of Henry county, Missouri, have been found a number of specimens representing a remarkable and apparently new species which presents a striking combination of tæniopteroid and alethopteroid characters. This species is of peculiar interest from the fact that it exhibits divisions of a type well known in certain Paleozoic and Mesozoic tæniopteroid forms arranged and developed in the manner familiar in the genus *Alethopteris*, as will be seen in the accompanying figures and following description:

Tæniopteris missouriensis, n. sp.

Pl. I, figures 1–7.

Diagnosis.—Fronds bipinnate (tripinnate ?), the larger divisions linear-lanceolate, acute, composed of pinnatifid pinnules near the base, above which are simple pinnules; primary rachis broad, shining, marked by somewhat irregular lines, and consisting of a thickened central portion, broadly but shallowly canaliculate above, half-round below, and of thinner marginal laminæ; pinnules opposite, sub-opposite or alternate,

slightly distant, at right angles or reflexed below, becoming more oblique above, ribbon-like, gradually tapering from the lower part, with borders straight or slightly undulate and nearly parallel, to a rather acute tip, long, sometimes reaching a length of 8 cm or more, and measuring 6 to 13 mm in width, the lower ones slightly narrowed toward the cordate, nearly symmetrical base with its narrowed attachment which overlaps the marginal lamina of the rachis, the higher ones becoming attached by the whole base, those near the top of the pinnæ becoming shorter, more distinctly decurrent and confluent, the margins more rapidly converging; limb of the pinnules rather thick, dull, broadly canaliculate along the midrib, somewhat convex near the borders, overlapping the marginal laminæ of the rachis, constricted to a rather narrow attachment in the lower and middle pinnules, spreading and uniting those near the apex of the pinnæ where it forms a wing incised by acute and decurring angles at the confluence of the pinnules; nervation tæniopteroid, midrib strong, depressed, broad and striate beneath, broadly canaliculate above, originating from the central portion of the rachis, passing along the middle of the lamina and tapering to the apex of the pinnule; lateral nerves rather fine salient above, distinct beneath, originating at an oblique or sometimes nearly a right angle from a slender cord-like bundle often distinctly in relief traversing the center of the canal, usually forking at or near the midrib, rarely simple, curving quickly if oblique, and passing fairly straight and generally parallel perpendicularly to the border, usually forking again at a varying distance in the lamina, and counting 24 to 28 per cm at the margin; basal nervils of the upper decurrent pinnules springing from the rachis; those of the uppermost alethopteroid pinnules becoming rather more oblique in passing to the margin.

Locality.—Represented by ten specimens from Hobbs' bank, nine miles south of Clinton, Missouri, and one specimen from Deepwater, about eight miles southeast of Clinton.

Specific Resemblances.—Among the known Paleozoic plants are several species described as *Danæites*, *Alethopteris*, *Tæniopteris* and *Desmopteris* which have many characters in common with *Tæniopteris missouriensis*. Of the American forms, *Danæites* (*Alethopteris*) *macrophylla*, Newb. sp., *Alethopteris maxima*, Andr., the types ranged under *Orthogoniopteris* and *Protoblechnum*, and an unpublished species of *Callipteridium* described by Lesquereux deserve comparison. Newberry's *Alethopteris macrophylla*,[1] the fully developed pinnules of which are somewhat similar to those of our specimens, is alethopteroid in arrangement, only the lowest, so far as I have observed, becoming contracted to the obliquely cordate base. Besides its more delicate habit, it further differs by the obliquity of the

1. Geol. Surv. Ohio, Pal. I, p. 383, pl. xlviii, figs. 3, 3*a*.

narrowed bases of the distinct pinnules, the more slender upper, confluent pinnules and the closer nervation. There is perhaps no generic difference between the two plants. *Alethopteris maxima*, Andr.,[1] as seen in a specimen from Rushville, Ohio, determined by Professor Lesquereux, is an alethopterid, though the difference between it and *Protoblechnum* may not be of generic rank. Still earlier in the geologic series a form perhaps somewhat similar existed in the *Alethopteris ingens*, Daws.,[2] the pinnules of which, more than one inch in width and three inches or more in length, have the *Danæites* nervation, or the *A. discrepans*, Daws.,[3] both from the middle Devonian of St. Johns, New Brunswick, the long, ribbon-like, open pinnules of which are united, however, by a narrow decurrent wing. So far as the form and development of the pinnules, and to some extent the nervation, is concerned, a closer resemblance obtains in the cases of *Pseudodanæopsis reticulata*, Font.,[4] from the Upper Trias at Clover Hill, Virginia, or the forms of *Tæniopteris münsteri*, Goepp. (*Angiopteris*, fide Schenk), from the Lias of Bornholm.[5] The upper pinnules of the Virginia species are united, as figured by Fontaine, while the lower ones are long, ribbon-like, and distinctly and nearly equally rounded at the base, as in our plant from Missouri. Perhaps its nearest affinity is, however, with the *Tæniopteris jejunata* of Grand Eury,[6] from the Upper Carboniferous and Permian of France. In this species, of which the upper parts of the pinnæ are, I believe, unknown, the pinnules are sometimes short-pedicelled, the lamina thin, and the nerves generally more oblique near the midrib and more regular, as figured, in passing to the margin than in our species.[7] In form the Missouri species is also close to certain species referred by Stur[8] and Zeiller[9] to *Desmopteris*, Stur, which has a somewhat different nervation, though it appears to be allied to the alethopteroid group.

Generic Reference.—In the characters of the rachis with its thickened, sulcate, center and marginal laminæ, in the origin of the nervils in the median canal of the pinnule, the ribbon-like lamina of which is rounded at the base where it overlaps the rachis, and, to a less extent, in the character of the nervation, the middle pinnules (figure 5) of our species are referable to *Tæniopteris* or to *Danæites*, according to one's interpreta-

1. Geol. Surv. Ohio, Pal. II, p. 421, pl. l, figs. 3, 3*a*-*b*.
2. Foss. Pl., Dev. Sil. Form., Can., pl. xviii, fig. 206, p. 54.
3. Op. cit., p. 54, figs. 203–205.
4. Older Mes. Fl., U. S. Geol. Surv. Monogr., vi, p. 59, pl. xxx, figs. 1–4.
5. Bartholin: Botanisk Tidsskr., vol. xviii, hft. i, Kjobenhavn, 1892, p. 23, pl. ix, fig. 9.
6. Fl. Carb. Loire, p. 121; Zeiller, Fl. foss. Commentry, pt. 1, p. 280; Atl., pl. xxii, figs. 7–9; Zeiller, Fl. foss. Autun, Épinac, p. 162, pl. xii, fig. 6.
7. The nervation seen in the figures of *T. missouriensis* is drawn with fidelity in detail from the originals.
8. Carbon.-Fl. Schatzlarer Sch., i. See *D. belgica*, Stur, p. 181, pl. lii, figs. 7–9.
9. Fl. foss. Valenciennes, p. 216, pl. xxxviii, figs. 3–5. See Ettingshausen: Fl. Radnitz, p. 40, pl xvi, figs. 2–4.

tion or restriction of those genera, while it has much also in common with certain Triassic and Jurassic forms referred by various authors to *Angiopteridium*, *Angiopteris*, *Marattia* and *Danæopsis*. One or two of the lowest pinnules found are sublobate or crenulate on the lower side, as though in the processs of subdivision, such as I take to be the case in the *Danæites* (*Alethopteris*) *macrophylla* figured by Newberry.[1] On the other hand, the upper, sessile, confluent or decurrent pinnules (figure 2), though springing from the central portion of the rachis (a condition indicated in some species of *Alethopteris*), are equally distinctly alethopteroid, being comparable to those pinnules seen in the upper part of primary pinnæ of various *Alethopterideæ*, such as *Alethopteris valida*, Boul.,[2] or in the *A. gigantea* and *A. longifolia* of Achepohl,[3] both of which may be allied with the group of long-pinnuled Paleozoic *Danæites*. It is probably generically inseparable from the *Danæites* (*Alethopteris*) *macrophylla*, Newb. sp.

But under the name *Danæites* we have two quite different groups of plants. The genus *Danæites*, as construed by Ettingshausen, Heer and Schimper,[4] embracing those forms in which the pinnules, having the characters of *Tæniopteris*, are rounded at the base and attached by the midrib only, differs widely from the interpretation put upon Goeppert's ambiguous genus by Stur[5] and Zeiller,[6] who, on account of the obscure fruiting figured by Goeppert,[7] have defined it to contain a number of pecopteroid forms with small pinnules and sori which, though not understood in certain respects, are strongly analogous to those of the living *Danæa*. The *Danæites emersoni* of Lesquereux,[8] referred to Goeppert's genus by reason of the appearance of its obscure fruiting,[9] represents, according to the figures, an alethopterid form related by habit and venation to *Callipteridium*, while the *D. macrophylla*, Newb. sp., was not placed by Lesquereux in *Tæniopteris*, to which it was considered referable in size and nervation, because it was pinnate, the unequally cordate base excluding it at the same time from *Alethopteris*. However, cordate or

1. Geol. Surv. Ohio, Pal. I, p. 383, pl. xlviii, figs. 3, 3*a*.

2. See Zeiller, Fl. foss. Valenciennes, p. 231, pl. xxxii, xxxiii, fig. 1.

3. Niederrh.-Westphal. Steink., p. 78, pl. xxiv, fig. 12; p. 134, pl. xli, figs. 1, 2.

4. In Zittel, Traité, ii, p. 85: "Feuille simple (ou double ?), pennée. Folioles inserées seulement par la nervure médiane, arrondies à la base, linéaires, devenant insensiblement pointues, possédant les caractères des *Tæniopteris*, à bord entier; nervure moyenne assez forte, nervures latérales se détachant de alles-ci à angle droit, nombreuses, les unes simples, les autres bifurquées. Fructifications disposées en deux séries le long de la nervure médiane."

5. Carbon.-Fl. Schatzlarer Sch., p. 221, figs. 33*a–c*.

6. Fl. foss. Valenciennes, p. 41.

7. Systema, p. 380; *Danæites asplenioides*, p. 380, pl. xix, figs. 4, 5.

8. Coal Flora, p. 157, pl. xxviii, figs. 1–3.

9. The *Pecopteris asplenioides* described by Fontaine and I. C. White (Permian Flora, p. 72, pl. xxv, fig. 1), from the Permo-Carboniferous, is perhaps closely related generically, by its fruiting, to *D. emersoni*, Lesq.

neuropteroid bases are not very rare in the lowest pinnules of *Alethopteris* and *Callipteridium*. In recent works interpreting the fossil according to the habit of recent ferns, a simple frond is not generally made an essential character of the genus *Tæniopteris*. So far, I believe, no one has described the upper portion of the pinna of any of the pinnately divided species now retained in the latter genus, the remains consisting generally of detached pinnules and fragments separated by reason of their deciduous tendency.

My reference of the Missouri species to *Tæniopteris* is provisional. The fern is in its habit, and to some extent its nervation, evidently closely related to *Alethopteris*. As remarked above, it should perhaps be included in the same genus with *Danæites* (*Aleth.*) *macrophylla* (Newb.) Lesq.; but from the character of the rachis, midrib, form of pinnules and the nervation, and from the observed development of the upper part of some of the tæniopteroid forms in the older Mesozoic and Carboniferous, I have been led to place it among the *Tæniopterideæ*, and notwithstanding the high degree of its superficial identity with them arattiaceous forms comparable in their fructification to *Danæa* or *Angiopteris*, it seems better, in default of all knowledge of the fruiting of our species, to refer it to the genus *Tæniopteris*, the former resting-place of many of the Mesozoic species, rather than to the equivocal genus *Danæites*. It is certainly ineligible to admission in the *Danæites* of Goeppert and Stur. The name *Danæites*, in the sense in which it is employed by Heer and Schimper, should, if used at all, perhaps be applied to those species only of which either the fruiting is known or the generic identity with other contemporaneous fruiting species is by other evidence satisfactorily proven, leaving their apparent representatives from the Paleozoic, the fruiting of which is not known, in the convenient and non-committal genus *Tæniopteris*, without presupposing any direct genetic relation to any particular fruiting genus.

Suggested genetic Relations.—The combination of alethopteroid and tæniopteroid characters in the plant from the Lower Coal Measures of Missouri more than strongly suggests a genetic relationship between the pinnate tæniopterids (including the Paleozoic *Danæites* of the type *D. macrophylla*), and in probable sequence the Mesozoic tæniopteroid *marattiaceæ*, on the one hand, and the Lower Carboniferous alethopteroid genera on the other; or, considering together with the alethopterids their close natural allies, the neuropterids, we may suppose the relationship to extend, as I shall try briefly to indicate, back to the megalopterid stock, in which they may have had their origin.

The genus *Megalopteris*, described from the Middle Devonian of Saint Johns, New Brunswick, by Sir William Dawson as a subgenus of

Neuropteris,[1] becomes, in the Lower Carboniferous, alethopteroid in its mode of development and configuration, while its nervation is that of *Alethopteris* or *Odontopteris*. The pinnules are further distinguished by their thick midrib, which is canaliculate above, semi-cylindrical beneath, narrowing in passing up, but distinct to the apex of the lamina. Lesquereux, who frequently pointed out its ancestry to, or at least its common descent with, the neuropterids, adds[2] that "except for the characters of the nervation [open, curving, close, dichotomous] this genus is not separable from *Danæopsis*, Heer. Saporta and Marion[3] include the genus *Megalopteris* with *Cannophyllites*, Brgt., in the *Cannophylliteæ*, which they regard as being near the *Dolerophylleæ* among their "Progymnosperms," a view in which Count Solms-Laubach and Schenk do not concur. Between the more alethopteroid forms of *Megalopteris*, such as *M. hartii*,[4] *M. ovata*,[5] *M. minima*,[6] *M. abbreviata*[7] and the alethopteroid genera found in the Lower Carboniferous of Ohio and West Virginia, the resemblance is so close as at once to force a comparison.

Among the forms from below the Maxville limestone in Ohio, the generic delimitations of which are perhaps more artificial than is common even among Paleozoic ferns, the *Alethopteris maxima*, And.,[8] is found to have a close tæniopteroid nervation in pinnules which are decurrent and confluent in the upper part of the pinna, but scarcely confluent in the lower part, where their mode of decurrence, in a semi-auricle, is nearly that given as a chief characteristic of *Orthogoniopteris*, regarded by Andrews, its author, as comparable to *Angiopteridium* and *Neriopteris*, with many of the characters of *Danæa*.[9] *Alethopteris holdeni* of Andrews[10] is described by Lesquereux[11] as agreeing in most respects with *Orthogoniopteris*, but is removed by him to form a new genus, *Protoblechnum*, its nerves being rather more curved than in *Orthogoniopteris*, while it is excluded from *Alethopteris* by its supposed simply pinnate fronds. It would, perhaps, be not incorrect to designate these "Waverly" forms, occurring in the same deposit with the above-mentioned species of *Megalopteris*, as *Alethopteroid megalopterids*. *Neriopteris*, from the conglomerate series of northern Ohio, with its sessile or short-petioled pinnules and oblique nervation, in fineness and regularity rivaling that of *Macrotæniopteris*, has,

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1. Foss. Pl. Dev. Upp. Sil. Can., p. 51, pl. xvii, figs. 191–194.
2. Coal Flora, I, p. 148. See Ann. Rep't Geol. Surv. Pa., 1886, pt. 1, p. 475.
3. Évol. rég. vég., Phanerog., p. 77.
4. Andrews, Geol. Surv. Ohio., Pal. II, p. 416, pi. xlvi, figs. 1, 1*a*.
5. Ibid., p. 417, pl. xlvii, figs. 1, 2, 2*a*.
6. Ibid., p. 416, pl. xlviii, figs. 1–3.
7. Lesquereux, Coal Flora, p. 151, pl. xxiv, fig. 3.
8. Ibid., p. 421, pl. l, figs. 3. 3*a*–*b*.
9. Ibid., p. 418, pl. l, figs. 1, 1*a*.
10. Ibid., p. 420, pl. li, figs. 1. 2, 2*a*.
11. Coal Flora, vol. I, p. 188.

according to Newberry, an equal degree of affinity to *Alethopteris* and *Tæniopteris*, and is separated from *Tæniopteris* only on account of its once or twice pinnate frond and the oblique nerves. It is interesting to note, in connection with this circumstance, the case of the *Alethopteris macrophylla* described from the same horizon by Newberry, who says that but for the rectangular nervation he should be inclined to include it in *Neriopteris*, while Lesquereux, on the other hand, refrained from referring it to *Tæniopteris* only because it was pinnate, placing it in *Danæites* instead. The backward rolling of the margin of *Neriopteris* may be only a more pronounced phase of what is common in species of *Alethopteris*, or it may be an indication of fructification. Newberry's description and figure of *Neriopteris lanceolata*[1] may with advantage be compared with those given by Lesquereux[2] under the name *Megalopteris? marginata*.

Systematic Position and Relations of the megalopterid Group.—A critical comparative study of the alethopteroid megalopterids will hardly fail to lead to the conclusion that in the early part of, perhaps before, the Subcarboniferous, the *Megalopteris* stock attained a high differentiation, in which the Alethopteroid group produced in *Neriopteris, Orthogoniopteris, Alethopteris, Protoblechnum* and *Danæites* (Heer-Schimp.) certain forms embracing the essential characters of the pinnate *Tæniopterideæ*. From this Lower Carboniferous group, doubtless including many undiscovered variations, may well have descended such forms as the *Tæniopteris missouriensis* in the Lower Coal Measures of the American continent, the *T. jejunata*, Grand Eury, and *T. carnoti*, Zeill., of the Upper Coal Measures of France, or the perhaps somewhat doubtful megalopteroid, *T. truncata*, Lesq.,[3] from the Conglomerate series.

As interpreted by superficial characters, the sequence of the Paleozoic tæniopteroid types into the Triassic forms, many of which have at some time rested in the genus *Tæniopteris* until the fruiting, either of themselves or of contemporaneous obviously generically identical species, has been discovered, proving them to be true ancestors of living genera in the *Marattiaceæ*, affords strong evidence at once both of the great antiquity of the group and its lineal descent from the *Megalopteris* stock.

The figures of Goeppert's *Tæniopteris münsteri*, from the Rhetic of Bavaria, given by Schimper[4] on referring the species to the genus *Marattia*, though apparently diagramatic in part, and those published by Bartholin[5] deserve a comparison with *Neriopteris* and *Danæites* of the type *macrophylla*, Newb. sp., and the species becomes more interesting

1. Geol. Surv. Ohio, Pal. I, p. 381, pl. xlv, figs. 1-3, 3*a*.
2. Coal Flora, I, p. 152, pl. xxiv, fig. 4.
3. Coal Flora, III, p. 743, pl. xciv, fig. 8.
4. In Zittel: Traité, II, p. 85, fig. 64; Traité pal. vég., Atlas, pl. xxxviii, fig. 1.
5. Botanisk Tidsskr., vol. xviii, hft. 1, 1892, p. 23, pl. ix, figs. 6, 9.

in view of the discovery in the Conglomerate series of Ohio of a form thoroughly Mesozoic in aspect that has been referred to the genus *Danæites* (Heer-Schimp.) by Lesquereux. From the study of many specimens of *Tæniopteris münsteri*, Goepp., fruiting from the Rhetic of Bavaria, Schenk was led[1] to refer the species without hesitation to the genus *Angiopteris*, being unable to find any character warranting a generic separation. Raciborski, on the other hand, is convinced that the fruiting of what he considers the same species in the Rhetic of Poland is that of the true *Marattia*. Another tæniopteroid species which merits consideration is the *Danæopsis marantacea* (Presl.) Heer, from the Keuper, the fruiting of which is distinctly marattiaceous, and which was regarded by Schenk[2] as very close to the living *Danæa*. The fine illustrations of this species given by Schimper[3] may with great interest be compared with the Megalopteroid group from Ohio. The habit of Schimper's specimen, representing the upper portion of a pinna, seems such as to suggest that the lower pinnules may be distinct and not confluent, a suggestion emphasized by the figures given by Schoenlein[4] and Saporta.[5]

As tending to confirm this view, I may add that in *Pseudodanæopsis*, a genus of plants from the Upper Trias of Virginia, separated by Fontaine from *Danæopsis* chiefly on account of its anastomosing nerves, the lower and middle pinnules of the species *P. reticulata*, Font., represented by numerous specimens in the United States National Museum (No. 3488), are distinct, distant, equilaterally rounded at the base and in all respects distinctly tæniopteroid, except for the frequent anastomosis of the nervils, although the upper portions agree to a great extent with the habit and characters of *Danæopsis marantacea*.

The establishment of the existence of the actual genera *Angiopteris* or *Marattia* in the Rhetic attributes to them a remarkable antiquity, unequaled, so far as I know, among any other living fern genera; but indisputable specimens of *Danæa*, with their fructification, were described by Zigno[6] from the Lias of Verona, proving for this genus a nearly equal antiquity. It follows that the epoch of indefinite length marking the genesis or lineal descent of these two marattiaceous genera must therefore have terminated by the close of the Triassic. However, since none of the forms of the *Danæopsis* or tæniopteroid *Danæites* types have been found with distinct fruiting earlier than the Keuper, the direct lineage of the actual genera cannot be traced backward into the Paleozoic with any greater definiteness than a high degree of probability or likelihood.

1. Die foss. Pflanzeur., p. 30, fig. 24*B*.
2. Op. cit., p. 35.
3. Traité pal. vég., Atlas, pl. xxxvii, figs. 1–3.
4. Abbild., pl. vii, fig. 2.
5. Vég. Jurass., I, pl. lxv, p. 454.
6. Fl. foss. oolit., vol. I, pl. xxv, pp. 208, 209.

In the absence of fruiting it may therefore justly seem inexpedient to many to refer pre-Keuper tæniopteroid species to genera like *Angiopteridium* or *Danæopsis*, founded on or implying a known direct relationship to a certain marattiaceous genus. It is for this reason that, as stated above, I have preferred the use of *Tæniopteris* as a generic name devoid of all implication of an antecedent relation of a species to any particular genus.

The probable relationship of the Carboniferous *Tæniopteris* to the Mesozoic *Marattiaceæ* has been well expressed by Professor Zeiller,[1] while that of the Mesozoic types of the genus has been ably discussed by Zigno,[2] Saporta[3] and others, nearly all of whom ally them directly with the living genera. The occurrence of pinnate tæniopterids, such as *Tæniopteris jejunata*, Grand Eury, and *T. carnoti*, Zeill., in the Carboniferous and Permian of France; *T. coriacea* and *T. fallax*, Goepp., in the Permian of Bohemia; *T. eckardi*, Germ., in the Permian of Tyrol, and the *Danæopsis Rajmahalensis*, Feist., in the Trias of India, the last two of which were regarded by Schimper[4] as agreeing entirely with the Keuper *Danæopsis*, completes the continuity of the discovered pinnate tæniopteroid forms from the Subcarboniferous types to the Keuper, and may be considered as belonging to a not improbable genetic series passing from the alethopteroid megalopterids of the Lower Carboniferous—perhaps from the genus *Megalopteris* itself—to fruiting forms, in the late Trias, of the living genera *Angiopteris*, *Marattia* and *Danæa*.

The relationship of the simple-leaved species of *Tæniopteris* to those with pinnate fronds is somewhat uncertain, though it does not seem improbable that all came from the same stock. It is not impossible that the species of the type *T. multinervis*, Weiss., or *T. smithsii*, Lesq., as well as the genus *Lesleya*,[5] may have come from the megalopterid type through an early variation. M. Zeiller, who has discovered forms referred by him to the latter genus in the Upper Carboniferous and Permian of France,[6] associates it with *Tæniopteris*, and indeed the obliquity sometimes seen in the nerves of *Tæniopteris*,[7] as well as the distinctly tæniopteroid aspect of *Lesleya*, gives strong support to this view. The descent of the two

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1. "Aucune des Ténioptéridées du terrain houiller n'a rencore été rencontrée à l'état fertile; mais quelques-unes d'entre elles présentent d'assez étroites affinites avec certaines Téniopteridées secondaires reconnues anjourd'hui comme très voisines au moins des genres *Angiopteris*, *Marattia*, ou *Danæa*, pour qu'on soit fondé à croire qu'elles doivent, elles aussi, appartenir aux Marattiacés." Fl. foss. bassin perm. Autun et Épinac, p. 160.

2. Fl. foss. oolit., vol. i.

3. Pal. franç., vég. Jurass., vol. i.

4. In Zittel: Traite, II, p. 86.

5. Lesquereux, Coal Flora, I, p. 143, Atlas, pl. xxv, figs. 1–3.

6. Fl. foss. bassin Autun Épinac, p. 166. See pl. xii, fig. 2; and Fl. foss. Commentry, pt. 1, p. 285, pl. xxiii, fig. 6.

7. See *T. multinervis*, op. cit., pl. xiii, fig. 1.

forms may reasonably be considered as common, if not lineal, the *Lesleya* appearing to date back nearer the type of *Megalopteris dawsoni*.[1] On the other hand, the conspicuously unequally rounded bases seen in some species of *Macrotæniopteris*[2] suggest that the leaves may be only petioled divisions, comparable in arrangement to the pinnules of *Neriopteris lanceolata*, Newb., and be derived from pinnate forms. It may not be going too far to add that from some Permian or Triassic species of *Tæniopteris* or *Macrotæniopteris*, essentially distinguished from the former only by the greater size and sometimes thinner texture, may well have originated the *Oleandridium*, thought by Schenk[3] to be probably marattiaceous.

As tending to confirm the hypothesis of the descent of the genera *Angiopteris* and *Danæa* from the *Megalopteris* stock may be noted the probable relationship of the neuropterids, whose origin, as *Neuropteris*, in or with *Megalopteris* is generally accepted by those who have studied specimens of the latter genus, to the *Marattiaceæ*. Although no satisfactorily definite fruiting of any of the *Neuropterideæ* has yet been discovered, the internal structure of the stems described by Renault[4] as *Myelopteris* or *Myeloxylon*, and afterwards identified as *Neuropteris*, *Odontopteris* and *Alethopteris*, is found to resemble that of the living *Marattiaceæ* more than any other known type of fern structure. Thus, from the evidence afforded by their internal structure, which has led M. Renault[5] to include *Alethopteris* among the *Neuropterideæ*, the marattiaceous nature of *Megalopteris* has already received strong support.

In this connection it is interesting to compare the illustrations of some of the more alethopteroid species of *Neuropteris*, such as *N. retorquata*, Daws.,[6] and *N. selwynii*, Daws.,[7] from the Middle Devonian, *N. antecedens*, Stur,[8] and *N. dluhoschi*, Stur[9] (cf. *N. elrodi*, Lesq.) from the Lower Carboniferous, *N. biformis*, Lesq.,[10] *N. matheroni*, Zeill.,[11] and the figures given

1. It is quite possible that from the *Lesleya* type may have been derived the *Glossopteris* group appearing in the Middle Carboniferous and Permo-Carboniferous of Australia. Lesquereux's diagnosis differs, as he remarks, from Brongniart's description of the latter only by the nerves not anastomosing. In this connection it is interesting to consult Newberry's *Tæniopteris glossopteroides* (Macomb Expedition, 1876, p. 147, pl. vii, figs. 2, 2*a*) from the Trias of Sonora, New Mexico. The supposed fruit dots represented in his figure 5 appear quite similar to the dots seen between the nerves of *Alethopteris maxima*, Andr.

2. See *M. magnifolia*, (Rogers) Schimp., Fontaine, Old. Mes. Fl., Monogr. U. S. G. S., vi, p. 19, pl. ii, fig. 1, pl. iii, iv, v.

3. Palæontogr., xxxi, 1881, p. 168.

4. Cours bot. foss., iii, p. 163.

5. Op. cit., p. 152.

6. Foss. Pl. Dev., Upp. Sil. Can., p. 50, pl. xvii, fig. 200.

7. Ibid., fig. 198.

8. Culm-Flora, p. 53, pl. xv, figs. 1–6.

9. Op. cit., p. 289, pl. xxviii, fig. 9.

10. Coal Flora, p. 121, pl. xiii, fig. 7.

11. Fl. foss. Commentry, pt. 1, pl. xxviii, fig. 7.

by Von Roehl under *N. plicata* [1] (= *N. rectinervis*, Kidst.) [2] from the Coal Measures, and *N. voltzii*, Brgt.,[3] and *N. salicifolia*, Fisch.,[4] from the Permian, with the phases often seen in the basal portions of some species of *Alethopteris*, as, for example, *A. lonchitica*, *A. grandini*, or *Callipteridium sullivantii*.[5]

On the basis of their fruitings, which are either exannulate or with only a rudimentary ring, as well as from the analogies of their structure, all modern authors agree in considering a large number of Paleozoic species with pecopteroid nervation as most nearly allied to the *Marattiaceæ* among living ferns.[6] This conclusion is natural, in view of the known antiquity of certain living marattiaceous genera, as well as the probable long existence of the eusporangiate ferns in Paleozoic time before the leptosporangiate forms appeared.

Graphic Presentation of Relations.—The following diagram represents in graphic form the general idea of development for a few genera; but it is not to be understood that the relations of individual genera are supposed to be in all cases as therein indicated, nor that the scheme is meant to imply a presumed proof or even the existence of evidence sufficient to form the basis of a proof. The lines should indicate in most cases a common rather than a lineal descent. It must be remembered that such a scheme is largely mere speculation. Many of the implied relations are improbable as well as incompatible. Some suggestions embodied in the chart constitute my only excuse for presenting it.

Conclusions.—In the foregoing discussion of what may be regarded as a tentative hypothesis for the line of descent of several of the living genera of *Marattiaceæ* from the *Megalopteris* stock, I have not presumed to attempt a proof or demonstration among a body of forms whose fruiting is essentially unknown; I have rather sought to bring together some of the evidence in favor of what I consider a good working theory. According to this hypothesis, we may suppose that the pinnate *Tæniopterideæ*, or a portion of that group (without prejudice of any important

1. Foss. Fl. Steink., Westfalens, pl. xx, figs. 7, 8; pl. xiii, fig. 8.
2. Trans. Roy. Soc. Edinb., xxxv, 1888, p. 314, figs. 2–4.
3. Hist., pl. lxvii.
4. Kutorga, Verh. Russ. Kais. Min. Gesell., St. Petersb., 1842, pl. i, fig. 2.
5. From the analogous characters of the nervation the genera *Neuropteris*, *Odontopteris*, *Lesleya*, *Dictyopteris*, *Neriopteris*, *Megalopteris*, and *Tæniopteris* were included in the Neuropterid group by Lesquereux in one of his last publications on the Carboniferous flora (Ann. Rep. Geol. Surv. Penna., 1886, pt. 1, p. 475). Renault (Cours. bot. foss., 3me année) makes the *Neuropterideæ* include *Neuropteris*, *Odontopteris*, *Dictyopteris*, *Alethopteris*, *Lonchopteris*, *Callipteridium*, and *Callipteris*. More recently Grand Eury (Géol. Pal. bassin houill. Gard., p. 286) construes the tribe so as to contain *Aulacopteris* (*Myelopteris*), *Alethopteris*, *Callipteridium*, *Neuropteris*, *Dictyopteris*, *Odontopteris*, *Tæniopteris*, and a new pecopteroid genus, *Parapecopteris*, intermediate in form between the neuropteroid *Pecopteris* species and those of *Neuropteris*, with fructification after the fashion of *Danæa*.
6. See Renault, Cours. bot. foss., 3e année; Stur, Carbon Fl. Schatzlar. Sch., ii; Zeiller, Fl. foss. Autun Épinac; Kidston, Trans. Geol. Soc. Glasgow, vol. ix, p. 1.

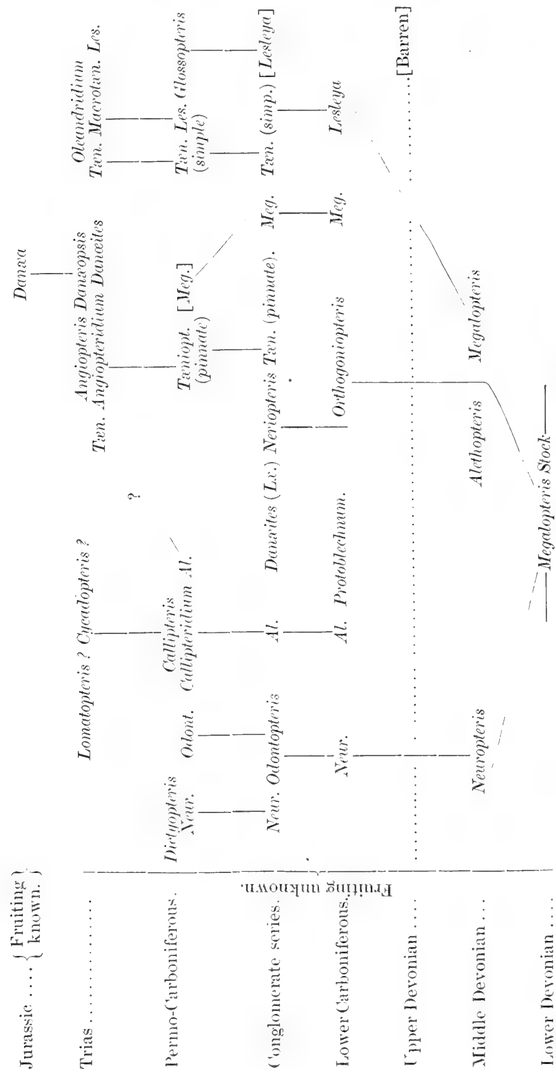

Diagram indicating hypothetical Relations.

systematic distinction between the pinnate and simple forms), came from an early *Megalopteris* stock, probably through the alethopteroid forms. The earliest flora, so far as I know, in which any of these occur, that of the Middle Devonian at Saint Johns. New Brunswick,[1] besides containing the *Megalopteris dawsoni*, has also representatives of *Neuropteris*, most of which are alethopteroid, and of *Alethopteris*, including the *A. grandis* and *A. discrepans* already referred to. It is not improbable that the three of these genera originated in a common stock; and since the *Megalopteris* group offers a comprehensive type from which the *Neuropteris* and *Alethopteris*, as well as the known *Megalopteris* species, might well have descended, that name may conveniently be employed in the hypothesis to designate the type existing previous to the Middle Devonian, from which the neuropteroid, alethopteroid and tæniopteroid groups, including in the latter some species of living marattiaceous genera, descended.

1. See Dawson, Foss. Pl. Dev., Upper Sil. Form. Can., Geol. Serv. Can., 1871.

Explanation of Plate 1.

Tæniopteris missouriensis, n. sp.

Figure 1.—Fragment from upper middle portion of pinna. Pinnules nearly distinct.

Figure 2.—Portion near tip of pinna. Pinnules confluent.

Figures 3 and 4.—Apex of pinna, showing true *Alethopteris* development.

Figure 5.—Fragment from middle of pinna, showing tæniopteroid pinnules, distinct, contracted at the base, attached to the central axis of the rachis.

Figures 6 and 7.—Fragments of detached pinnules. The broad character of the median canal is not well indicated, nor the wide midrib, especially prominent on the back of the pinnule. The origin of the nervils in the median strand is well represented.

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SOME ELEMENTS OF LAND SCULPTURE

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CONTENTS

INTRODUCTION.

Relief Forms subject to fixed Laws.—Every element of form which gives character and expression to a landscape is determined by fixed laws. It is true that the arrangement of hills and vales does not conform to any simple geometric pattern. The sculpturing forces are complex, and the net result of their interaction is necessarily also complex and promis-

cuous; still the action of each single force is regular, exact and unvarying, and the complex results are harmonious.

Predominance of Curves over Angles.—Most pleasing to the eye are those forms in a landscape which are bounded by curved lines and surfaces. Most striking, picturesque, rugged and impressive are those which are bounded by planes and angles. The former are far more common, and are produced by weathering and the washing of water. The latter depend upon the primitive structure of the rocks. Angular structural forms are the rough blocks which nature furnishes. Wind and frost, sun and rain, rills and rivers, are the tools which carve out of these rough blocks the beautiful landscapes which adorn the earth and make it a fit abode for man.

Structural Angles.

Character of Rock governs Form.—The laws of structure are intricate, and structural forms are infinite in variety. The planes may face in any direction, the angles may be acute or obtuse. That depends wholly upon the forces of upheaval and the laws of fracture in the different rocks; granite, limestone, basalt, conglomerate, each imparts a definite and characteristic expression to the landscape, because each breaks in a way peculiar to itself.

Incessant Activity of sculpturing Forces.—But with all this variety in detail there are certain broad, general features of structure which exert an important influence in the evolution of earth forms. The pent-up forces within the earth thrust up from time to time fresh blocks, to be disintegrated by the weather and carved by running water. These sculpturing forces never rest, while the forces of upheaval are intermittent. This incessant and universal activity of the sculpturing forces is the reason why the pleasing forms bounded by curves are more common than rough structural angles.

Flatness Characteristic of continental Blocks.—Though the internal forces are inconstant they are mighty. Mountains and continents are the burdens which they lift with ease. The lands are lifted and at the same time broken, faulted, bent and tilted this way and that. The resulting planes may slope north, south, east or west, and the pitch may be steep or gentle. Very steep structural planes are, however, of limited extent, while the great continental blocks must of necessity lie nearly flat, though the edges may be precipitous. Broad, flat blocks are therefore the usual raw materials for the sculpturing forces, and the resulting weather and water curves are dominated by these massive and nearly level, primitive elements of structure. Massive breadth and relatively slight inclination of the general surface are the fundamental character-

istics of structure which prevail in the midst of the infinite variety of relief forms.

Weather Curve and water Curves.

Weather Curve.—The weathering of structural blocks reduces their salient angles, which are attacked from both of the adjacent faces at once. At the point *x*, figure 1, the disintegrating forces act with twice as great intensity as at *b*, since the attack comes from two directions. The effects are more than twice as great at *x*, because the products of decay are quickly removed, exposing fresh surfaces to the attack, while at *b* they remain to cover and protect the subjacent beds. Thus the structural block *m n o p* is rounded off by weathering. The new outline *a b c* is composite. The portion *d b e* is a weather curve, convex upward. If weathering alone, without the aid of flowing water, has been concerned in the sculpturing process, the talus slopes *a d* and *e c* will be structural planes, not curves. The structural angle *e c p* will be determined by the

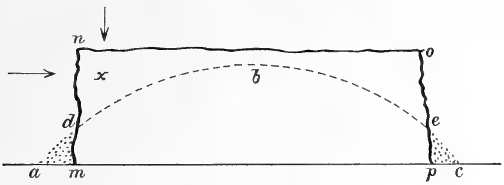

Figure 1.—*Weather Curve.*

resting angle of the materials composing the talus, and that again will depend upon the size and form of the particles; but in humid regions the talus slopes will be quickly molded into water curves, as hereafter described. The resulting form *a b c* will be a rounded rock, a smooth knob, or a round-topped hill or mountain, according as the original block was measured by inches or leagues.

Convexity of weather Curve.—The upward convexity of weather curves may be deduced also from the law that declivities vary directly as hardness. If we suppose the lowest beds composing a structural block to be very soft and the hardness to increase upward by regular gradations, a concave slope would result. Such a curve may actually be formed, but it would have to be ascribed to structure, not to weathering. Weather curves are often interrupted and modified by such structural accidents. But if the opposite conditions prevail—that is to say, if the soft bed is above and the hardness increases regularly downward—the law just enunciated will yield a slope of convex curvature. Now, whatever may

be the primitive conditions of hardness in structural blocks, the tendency of weathering is to soften them from the top downward, or, in other words, to produce that set of conditions last supposed; hence the weather curve should be convex upward.*

Water Curves: horizontal and vertical.—The streams formed by the rains falling upon continental blocks have still greater sculpturing power than the weather. The rough edges are first scored down with ravines, as a carpenter hacks timber with an axe before he dresses it with finer tools. Some of the ravines lengthen into rivers and cut far back into the land. Except raw and fresh ravines, which may be tolerably straight, the path of flowing water is meandering. Graceful serpentine curves mark the flow-line, curves which constitute the most charming elements of scenery. These horizontal water curves address themselves to the eye in the most clear and agreeable manner; but there is another kind of water curve, the vertical, not always visible to the bodily eye, but none the less clear and real to the eye of the mind. If we follow up a short

FIGURE 2.—*Water Curve of Erosion.*

ravine cut in homogeneous material we shall find a gentle slope at first, which gradually increases in steepness up to the crest of the escarpment. The positions of successive points of the channel, with their true relative distances above base-level, if drawn to scale, would form a curve like figure 2. This is the typical water curve of erosion.

Concavity of water Curve.—The water curve is precisely opposite to the weather curve, in that it is concave upward. In a short ravine it may be plainly seen, but the vertical curve of a river is so much flattened and extended that it can only be comprehended by the mind, not perceived by the eye. Indeed, there is a sense in which this vertical water curve, as defined by Gilbert, La Noë and Margarie and others, is not only imperceptible but purely ideal. It is seldom realized as a smooth curve, uniformly increasing its gradient upstream, except for short streams whose channels are cut in a homogeneous rock. The intervention of a harder stratum makes a jog in the curve. All cataracts and rapids with

*Compare La Noë and Margarie, "Formes du Terrain," p. 26, pl. vii, fig. 15.

still water above them are in flat contradiction to the law of increasing gradient upstream and skyward concavity. Time enough being given, the obstruction would no doubt be cut through and the ideal curve established. All streams tend toward its realization as an ultimate goal. Cataracts are temporary departures from the rule, and quite evanescent when compared with the whole life history of a river.

Combined weather Curve and water Curve.—Another departure from the type is more permanent and universal, so frequent and lasting, indeed, that it almost deserves to be formulated as a distinct and opposite law. It is the fact that while the gradient increases upstream to a certain point and the curve is concave upward, as the definition requires, above that point the gradient diminishes, and the curve is convex upward, as at *a b*, figure 3. This is usually true of streams rising in extensive swamps and wet meadows. Even the mountain streams often flow sluggishly at first upon broad flat summits, then pitch headlong over the escarpment. We have seen above that breadth and flatness are the dominant elements of structure. The precipitous edges of broad continental

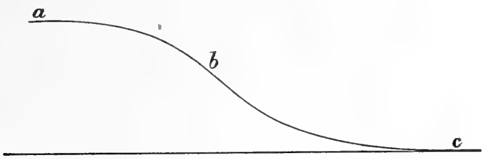

FIGURE 3.—*Combined weather Curve (a b) and water Curve (b c).*

blocks being rounded off impose their own curves upon the rivers. Thus the convex portion (*a b*, figure 3) is not really a water curve. It is a temporary accommodation of a water gradient to the structural form upon which it flows. The true water curve (*b c*, figure 3) will moreover gradually encroach upon the upper convex curve *a b*, and, if the base-leveling be continued long enough, it will establish itself as a smooth concave curve from *c* to *a*. Hence this exception, as in the case of cataracts, is an incident only of river history, the only differences being that it is more common and less transient; but, as I said above, it almost deserves to take rank as a distinct and coördinate law on account of its universality. The convex portion of the curve (*a b*, figure 3) is not, however, a new kind of curve, but one that has already been defined, viz, the *weather curve*. The double reversed curve (*a b c*, figure 3) is the combination of the weather curve and the water curve of erosion. It is Hogarth's line of beauty, the most universal of earth forms. Almost every hill slope in a rolling country presents an upper convex portion

(weather curve) and a lower concave portion (water curve). Some landscape engineers have caught nature's hint and give a terrace the form shown in figure 3, which is at once more elegant and more solid and durable than a slope in which the convexity is carried uniformly down

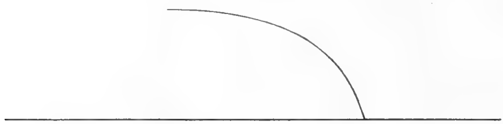

FIGURE 4.—*Unstable artificial Curve.*

to the base, as in figure 4. The latter is unnatural and unstable, while the former is natural and stable.

Reversed Curves.—This combination of the weather curve with the vertical water curve of erosion when carried out upon both sides of a structural block (as *m n o p*, figure 1), which is symmetrical and homogeneous, will give the pair of reversed curves shown in figure 5, instead of the

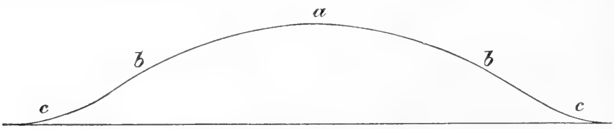

FIGURE 5.—*Normal relief Form in an advanced Stage of Base-leveling.*

simple convex weather curve *d b e*, figure 1. Figure 5 is the normal pattern of relief forms in a region of advanced land sculpture. The summit *b a b* is a simple, typical weather curve. The talus of figure 1, with its clear-cut structural angle, *e c p*, has been replaced by the vertical water curve *b c* (figure 5), which is concave upward.

Gilbert's "Exception" explained.—This same combination of weather and water curves is the true explanation of the "exception" noted by Gilbert,* who states:

"There is one other peculiarity † of bad-land forms which is of great significance, but which I shall nevertheless not undertake to explain. According to the law of

FIGURE 6.—*Typical Profile of the drainage Slopes of Mountains.*

* Report on the Geology of the Henry Mountains, pp. 122–123.

† Figure 6, which is a reproduction of Gilbert's figure 54 (ibid., p. 116), shows an angle. Such would be the actual result of intersecting water curves but for the effect of weathering, which rounds off the angle and replaces it by a curve convex upward.

divides, as stated in a previous paragraph, the profile of any slope in the bad-lands should be concave upward, and the slope should be steepest at the divide. The union or intersection of two slopes on a divide should produce an angle [figure 6]. But in point of fact the slopes do not unite in an angle. They unite in a curve, and the profile of a drainage slope, instead of being concave all the way to its summit, changes its curvature and becomes convex. . . . From *a* to *m* [figure 7] and from *b* to *n* the slopes are concave, but from *m* to *n* there is a convex curvature. Where the flanking slopes are as steep as represented in the diagram, the convexity on the crest of a ridge has a breadth of only two or three yards, but where the flanking slopes are gentle, its breadth is several times as great. [Compare figure 5 with figure 7.] It is never absent.

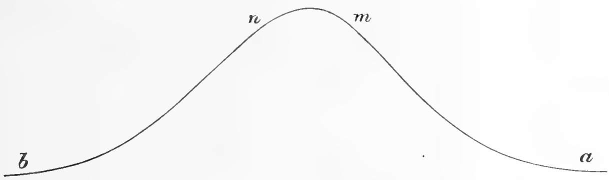

FIGURE 7.*—*Cross-profile of bad-land Divide.*

"Thus in the sculpture of the bad-lands there is revealed an exception to the law of divides,—an exception which cannot be referred to accidents of structure, and which is as persistent in its recurrence as are the features which conform to the law,—an exception which in some unexplained way is part of the law. Our analysis of the agencies and conditions of erosion, on the one hand, has led to the conclusion that (where structure does not prevent) the declivities of a continuous drainage slope increase as the quantities of water flowing over them decrease, and that they are great in proportion as they are near divides. Our observation, on the other hand, shows that the declivities increase as the quantities of water diminish, up to a certain point where the quantity is very small, and then decrease; and that declivities are great in proportion as they are near divides, unless they are *very* near divides. Evidently some factor has been overlooked in the analysis,—a factor which in the main is less important than the flow of water, but which asserts its existence at those points where the flow of water is exceedingly small, and is there supreme."

The missing factor is a simple and omnipresent one, namely, *weathering*. From *a* to *m* the water curve predominates, and its law of skyward concavity and increasing declivity is supreme. From *m* to *n* the weather curve predominates. As Gilbert remarks, "the flow of water is exceedingly small" there. It falls as rain and beats upon the crest, but that is a kind of weathering.

Besides supplying the missing factor which explains the puzzle and reconciles the results of scientific analysis with the facts as learned by

*Figure 7 is a reproduction of Gilbert's figure 60, in his Report on the Geology of the Henry Mountains, p. 123.

observation, I will add two observations suggested by the above quotation.

In the first place, the remark of Gilbert that "where the flanking slopes are as steep as represented in the diagram, the convexity on the crest of the ridge has a breadth of only two or three yards, but where the flanking slopes are gentle, its breadth is several times as great," conveys a partial truth, and at the same time suggests a broader truth. Gilbert merely affirms a relation between the steepness of the decivities and the breadth of the convex portion of the crest; but both of these correlated elements of form depend upon the relative intensities of water sculpture and weathering, and these in turn depend upon the structure and the stage of base-leveling in the given region. The general law of relative intensities may be stated as follows: If water sculpture predominates, the slopes will be steep and the divides narrow and high; and, conversely, if weathering predominates, the slopes will be gentle and the divides broad and low; but this general law is profoundly modified by structure and time. The broad, flat blocks which, as we have seen

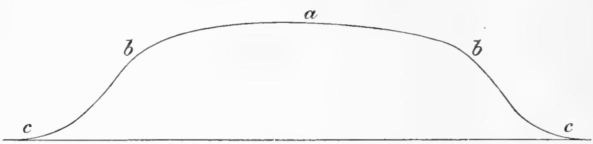

FIGURE 8.—*Illustrating the Co-existence of steep Slopes with broad weather Curves in an early Stage of Base-leveling.*
$b\ a\ b$ = weather curve; $b\ c$ = water curve.

above, are the normal types of raw material to be moulded by land sculpture, yield broad weather curves in the early stages of base-leveling wholly on account of their primitive structure. This is an exception to the general law, inasmuch as water sculpture is usually energetic in these early stages, and yet the weather curves are broad. It is also an exception to Gilbert's statement that the crest is narrow if the slopes are steep. Many cases occur in the earlier stages of base-leveling in which broad, flat weather curves are conjoined with very steep water curves, as in figure 8. Many cases also occur in the same early stages of base-leveling in which the crest is narrow and the slopes steep, as affirmed by Gilbert and illustrated by his figure 60. For example, the same mesa represented in cross-section by figure 8 would present many subordinate ridges between its lateral ravines with steep slopes and narrow crests. It is evident, therefore, that in this early stage of base-leveling, structure is the dominant factor whether the crest is narrow or broad. The steep water curves are the direct result of structure, since it is only by upheaval

that such high gradients originate; and the broad crests are equally the direct effects of structure. The narrow crests exemplify the law of relative intensities, as stated above. Water sculpture is more energetic than weathering upon the precipitous edges of structural blocks; hence the slopes are steep and the crests narrow.

With the lapse of time the influence of structure gradually diminishes, and the stage which base-leveling has attained exerts the greater modifying influence upon the general law. In other words, time exerts a modifying influence in proportion to its quantity, measured from the beginning of the process of base-leveling. If this process has just begun, structure is supreme; but if it has reached its later stages the accumulated effects of time are supreme. Weathering and water sculpture both tend to become less energetic as the surface approaches base-level and the gradients flatten out, but the former retains a greater relative efficiency. The transportation and removal of the solid products of weathering does indeed steadily diminish, but solution—one form of weathering—and the transportation of its products goes on to the very last stages of land sculpture, after erosion has ceased. These last stages are therefore marked by water curves of slight declivity and weather curves of great breadth and flatness, both in fact closely approaching, but never quite reaching, an absolute base-level.

The general law with its modifications may be summed up thus: In early stages of base-leveling the predominance of water sculpture gives steep slopes and narrow crests, except where the latter have a breadth which is imposed upon them by the structure, and in late stages of base-leveling the predominance of weathering gives water curves of gentle declivity and broad, low weather curves.

The second observation suggested by the quotation from Gilbert is that the principles explained by him as applying to "bad-land forms" are equally applicable to all kinds and all stages of land sculpture. Bad lands constitute a certain striking phase of land sculpture, but they are nowise exceptional, so far as the general laws and processes of land sculpt ture are concerned. All of the factors are present and active. The resul is unique, not because of the absence of any familiar factor nor because of the presence of any new factor, but solely because of the relative intensity of the factors. Structure and water sculpture strongly predominate over weathering. Structural forces have supplied the cañon clays and marls as raw material—a matrix soft, homogeneous and peculiarly susceptible to rapid erosion on account of these properties and its considerable elevation. Water sculpture, attacking it with an energy proportional to its height above base-level and its lack of cohesion, cuts deep gashes so rapidly that weathering has little opportunity to round off the

sharp edges. Indeed, this important factor occasionally seems, for the time being, to be wholly wanting. Forms like figure 9 are not uncommon in the bad lands. The summit *b b* is protected with turf and the water curves *b c* extend to the very crest without a trace of a weather curve; but the elimination of this factor is transitory. Visit the same butte some years later and you will find, if water sculpture is still vigorous, that the two water curves have so nearly joined that the turf has disappeared and a short weather curve occupies the narrow crest, as in figure 7 (Gilbert's figure 60), or, if water sculpture has been dormant, the angles *b b* are replaced by weather curves. In a bad-land region all stages of the process may be observed, from the level-topped sharp-angled butte, often receiving the significant name "Box butte" or "Trunk butte," shown in figure 9, to low domes like figure 5, which are not bad-land forms at all. The same laws, the same processes are concerned in all these varied results, and a philosophic view of the subject demands that

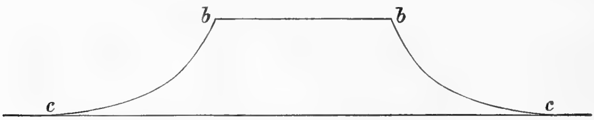

FIGURE 9.—*Miniature Butte in the Bad Lands.*

all phases and stages of land sculpture be grouped comprehensively instead of singling out a particular phase, though that may be a striking one.

Water Curve of Deposition.—The water curve of erosion, having its skyward face concave, is not the only vertical water curve. There is also the curve of deposition, which is convex upward. Where a mountain torrent debouches upon the plain, the *débris* carried or rolled along by it spreads out in a mass which is fan-shaped in ground plan and conical in elevation.

Alluvial Cone.—Such a deposit is usually called an alluvial cone, but, in view of its radial extension from the mouth of the gorge, Hilgard calls it a *débris* fan. The cross-section presents a typical water curve of deposition, convex upward.

Flood-plains.—The flood plains of rivers, so far as they are built up by sediment spreading laterally from the channel during floods,* follow the

* This is the usually accepted meaning of the term flood plain, namely, that it is the work of a constructive river which is silting up its valley, or certain portions of it, during inundations. Gilbert uses the term in a very different sense. He says in Geology of the Henry Mountains, p. 132:

"* * flood-plains are usually produced by lateral corrasion. There are instances, especially near the seacoast, of river plains which have originated by the silting up of valleys, and have been afterward partially destroyed by the same rivers when some change of level permitted them to

same law. It is true the curvature is faint, so faint that in the field it may be imperceptible to the eye, and in diagrams most authors ignore it, and represent the cross-section of a flood-plain by a straight line; but the curve, though slight, is real. If compared with the *débris* fan of a mountain torrent it would be found to correspond to the outer margin, where it blends into the plain and the convexity is slight. Strictly speaking, a flood-plain extending many miles along a river cannot be likened to a single alluvial cone; it is a composite structure made up of a multitude of overlapping cones, each having its apex upstream at that point where the silt composing it left the channel. The overlaps obscure the convexity of individual cones, and the net result is a curve of large radius and low convexity.

Cross-section of constructive River.—The typical cross-section of a river having a flood plain—a constructive river—so far from showing a straight line from the channel to the bluffs, presents a convex curve of deposition, besides a number of other distinct elements. If no terraces are present the section will be as in figure 10, each half of the valley presenting a

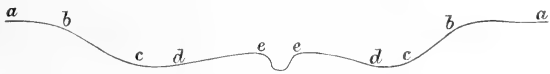

FIGURE 10.—*Cross-section of a constructive River.*

a b = Weather curve at crest of bluffs; *b c* = Water curve of erosion; *c d* = Swamp; *d e* = Water curve of deposition.

weather curve, two water curves of opposite character, and a swamp along the line of intersection of the water curves. The presence of terraces adds much complexity. The swamp at *c d* is caused by a depressed surface and an impervious subsoil. Only the finest argillaceous sediments spread so far from the channel or from the bluffs, and these

cut their channels deeper; and these instances, conspiring with the fact that the surfaces of flood plains are alluvial, and with the fact that many terraces in glacial regions are carved from unconsolidated drift, have led some American geologists into the error of supposing that river terraces in general are records of sedimentation, when in fact they record the stages of progressive corrasion."

The question about the true significance of terraces is aside from the present discussion, but the ordinary meaning of flood-plain is too well settled to disturb it by so radical a departure as that here proposed. Since Gilbert himself admits it to be descriptive of a real phenomenon, we might conclude that there are two kinds, flood-plains of corrasion and flood-plains of sedimentation, and that all we need is to distinguish these and use the term in each case with its proper adjunct; but a closer analysis reveals two difficulties. In the first place, since the products of corrasion on one side of a stream are deposited as sediments on the other side, it turns out that the plain of corrasion, or planation, is also a plain of sedimentation. This difficulty tends to merge the two kinds into one; but there is an opposite and more radical difficulty which rends them apart. The plain of planation is not properly a flood-plain at all. Lateral corrasion is not exclusively a flood phenomenon, though it is active in floods. The plain of planation differs so much from true flood deposits that the term flood plain ought to be restricted to the latter, as is usually done.

form a gumbo,* which imparts the impervious quality to the subsoil, and at the same time their small bulk and relatively slow growth occasions a line of depression. Even when well drained, this part of the river bottom is apt to be cold and sour until redeemed by tillage and the admixture of silicious elements.

True Form of Cross-section.—The old definition of the upper course of a river postulates a V-shaped cross-section. This is not strictly true, even of fresh ravines at the headwaters. The sides are water curves of erosion, and they conform to the general law that the slope varies inversely as the quantity of water flowing upon it. Since the bottom of a slope receives the water from above as well as its own quota of the rainfall, its pitch must always be less steep than that above if it is a true water curve. One side of a ravine may be a *talus* with its sharp structural angle and uniform declivity, the corrasion at its base proceeding so rapidly as to give no time for a water curve to form. Very rarely, when the bottom only of a ravine is undergoing erosion, a *talus* slope may exist on both sides, and the section will then be accurately V-shaped; but if the corrasion at the base of either wall lags or stops, the wash of that slope will speedily convert it into a concave water curve of erosion. The actual result is usually composite, including elements or remnants of a structural angle, modified by a water curve. At all events, it is a curve rather than an angle, and a V with curved sides quickly passes into a U. The middle course of a river is usually said to have a U-shaped valley, but in fact this form belongs to all parts of a river, the only difference being the breadth of the U. It is in the upper course alone that it has anything like normal proportions. In the middle, and especially in the lower course, it sprawls out and flattens down until all resemblance to the fifth vowel is lost. Moreover, the presence of terraces and water curves of deposition so complicates the cross-section that the comparison of it with any letter of the alphabet is no longer useful.

Cross-section of River having no Flood-plain.—The most important real distinction between the different parts of a river valley is the presence or absence of a flood-plain. If this is present the section will be as in figure 10; if it is absent, it will be as in figure 11, in which, as compared with figure 10, the middle portion, including the flood-plain with its convex curvature, has been cut out.

There is a wide range of variation among different rivers in that portion of the valley which has a cross-section like figure 11. It may be very narrowly U-shaped, or it may open out to such breadth as to become anomalous. Under ordinary climatic and geologic conditions the

*Gumbo is a peculiar, tenacious, fine-grained clay. The use and meaning of this term in the western states is so well established, that it promises to become a useful and expressive word.

narrow U-form would include the whole course of the river above the initial flood plain.

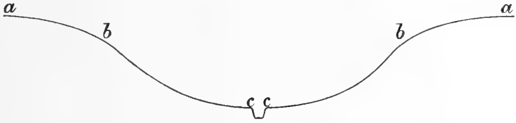

FIGURE 11.—*Cross-section of a river Valley having no Flood-plain.*

Each half of the valley has only two elements, the weather curve *a b* and the water curve *b c*.

Anomalous Valleys of the great Plains.—But certain peculiar conditions sometimes intervene to prevent the development of a flood plain where it normally belongs. Then we have the anomaly of a valley some miles in breadth without a flood-plain, which is so diametrically opposed to our ordinary conceptions of rivers that we are at once impelled to seek its explanation. It is upon the great plains at the eastern base of the Rocky mountains that we find the most striking examples of wide valleys without flood-plains. The lower part of the water curve (*m n*, figure 12)

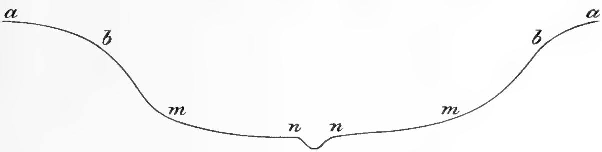

FIGURE 12.—*Cross-section of a broad Valley of the Plains having no Flood-plain.*

a b = weather curve; *b m n* = water curve, of which the lower portion, *m n*, is greatly extended.

may be a mile or two in breadth. At the point *m* the valley wall begins to be well defined. The valley floor *m m* is also well defined, but quite remarkable for its wide departure from horizontality. The point *m* may be fifty feet above *n*. It is unmistakably a valley floor, but its steepness is astonishing and perplexing. Moreover, the anomaly does not stop with the unusual form of the cross-section. The quality of the land contradicts all expectations which would naturally be entertained respecting river bottoms. Instead of a uniform stretch of rich alluvium we find irregular alternations of loam, sand, gravel, gumbo and alkali patches. The best element, the loam, may indeed predominate, and hence the valley may support a prosperous agriculture; but the valley lands of the plains are generally inferior to the table lands, thus reversing the conditions which usually prevail.

The plains are built up of incoherent masses of sand, gravel, clay

and marl, in which the rainfall is absorbed and reaches the rivers by slow percolation, instead of flowing quickly and copiously on the surface; hence, if there are any floods at all, they are infrequent and irregular. Without regular floods there can be no distinct flood-plain, the silt deposited during the rare overflows being obscured and subordinated to the heterogeneous wash from the hills. The patchy character of the soil arises from local conditions affecting the wind drifts and washings from the bluffs, bringing down here gravel, yonder sand, and again the mingled silicious, calcareous and argillaceous elements constituting loam. Alkaline carbonates and sulphates are developed in low, undrained spots, where water lies and evaporates. By the meanderings of the channel the valley floor is plowed up and redeposited, but this process tends to still greater differences rather than greater uniformity. The assorting action of the currents segregates the coarser and finer elements and deposits each by itself. The absence of floods intensifies and perpetuates these diversities. No general blanket of rich silt is spread in annual layers to cover and blend into one the heterogeneous soils, nor do the copious waters spread over the alkali patches to dilute and wash out their bitterness. Thus arise these anomalous, wide valleys without flood-plains, in which the whole valley floor from the bluffs to the channel on either side slopes sharply inward, and the soils are patchy and wholly unlike ordinary bottom lands.

Summary.

This paper makes no pretensions to an exhaustive treatment of the elements of land sculpture. There are other forces at work, and the forces named operate in ways not herein discussed in detail; but in the broad, general view of the subject the face of nature is moulded chiefly by these forces: (1) Upheaval, which furnishes the structural blocks to be chiseled into pleasing forms; (2) Weathering, which rounds off the asperities and covers the land with graceful, swelling curves; (3) Washing of water, which yields concave flowing lines upon slopes of erosion, and low convex curves of deposition.

The combination of the weather curve with the water curve of erosion is here noted and explained for the first time. It constitutes the greatest charm of natural landscapes, and its effects are universal.

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SOME DYNAMIC AND METASOMATIC PHENOMENA IN A METAMORPHIC CONGLOMERATE IN THE GREEN MOUNTAINS*

BY CHARLES LIVY WHITTLE

(Presented before the Society August 16, 1892)

CONTENTS

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Metamorphic Conglomerate.

Approximate Relation to known geologic Horizon.—The geologic position of the limestone and quartzite of the Rutland valley has lately been determined definitely,* the limestone paleontologically and the quartzite stratigraphically.

Occurring next below the limestone, the quartzite is the northern continuation of the Clarksburg-mountain quartzite, in Massachusetts, in which Walcott has found the Olenellus fauna characteristic of the Lower Cambrian horizon. About one mile north of Rutland village, in Vermont, Dr Wolf and Dr Foerste were fortunate enough to find Lower Cambrian fossils in a silicious limestone that lies superjacent to the quartzite. Northeast of Rutland the quartzite is found associated with a sandy phyllitic schist that belongs to a series of metamorphosed clastics having a vitreous quartzite or conglomerate at its base. This whole series, barring the Lower Cambrian quartzite and limestone, has been subjected to the most intense dynamic action. The sequence of the different members of the series is in many regions hopelessly obliterated and confused by the mountain-building forces that have produced new structural planes, a new mineralogic composition, and have additionally complicated the geologic order of succession by sharp folding, which is, as a rule, too much involved for decipherment. These phenomena are particularly noticeable in the conglomerate horizon and its many phases, and it is in this rock that I wish to describe some of the evidences and effects of metamorphism shown by the destruction of old clastic minerals and in the production of new ones.

OTTRELITE SCHIST.

Occurrence and Extent.—One of the most conspicuous phases of the conglomerate is due to the development of ottrelite in great abundance, so that it is not uncommon to find fully 25 per cent of the rock made up of this mineral. The ottrelite is commonly most abundantly developed where the rock has now a well-marked schistose character that is either due to an original finer-grained deposit or is a result of the shearing and crushing action of dynamic forces. It is often found, however, occurring in the groundmass of the coarsest conglomerate or along planes of shearing in a blue, hyaline quartzite. Still another phase is more nearly massive, fully 40 per cent being ottrelite, the rock at first sight simulating in appearance some porphyritic hornblende dike. The rock is a very

* "On the Lower Cambrian Age of the Stockbridge Limestone": Bull. Geol. Soc. Am., vol. 2, 1890 pp. 331–338.

variable one, but, considered as a whole, it forms one of the most important stratigraphic horizons found in the more crystalline areas of the Green mountains. In lateral extension it has been traced, with unimportant breaks, all the way across the Green-mountain anticlinal axis, as mapped by Hitchcock,* from Mendon, Vermont, to North Sherburne, Vermont. In vertical extension it has considerable thickness, although accurate determination is very difficult, owing to the obliteration of planes of bedding in most instances and the complexity of the flexures; but it seems safe to assume a thickness of several hundred feet, at least in several localities that have been most carefully studied, viz: a spur extending south from Mount Carmel, in the town of Chittenden, and the east and west crest forming the southern portion of the mountain, somewhat inappropriately named "Old Aunt Sal."† The latter mountain is situated in the town of Mendon, the next town south of Chittenden. The phases studied thus far in the laboratory are from this latter locality and from the western part of the "Rabbit ledge," just south of Mendon "city."

Physical and microscopic Characters.—In the hand specimen the ottrelite of the most massive occurrence of the ottrelite-bearing rock appears either as isolated areas, generally with rudely circular outlines, or as groups of them in a background of fine-grained pinkish-brown to dark-purple quartz, in places constituting nearly pure ottrelite. These areas possess approximately a common diameter of about three-sixteenths of an inch. In structure they are made up of radiating imbricated plates generally arranged in essentially one plane for any single area; but the positions of the different areas seem in the main to be accidental, although locally they may be arranged parallel, as shown by a tendency in the rocks to cleave into rude slabs, a tendency augmented by thin folia of serecite.

A well marked spherocrystalline habit characterizes all the ottrelite areas. In some this radiated growth seems to be perfect. Microscopically the radiated structure is much more evident. Composite and fan-shaped areas, penetrating one another irrregularly, coëxist with isolated prisms and beautiful spherocrystalline aggregates, yielding imperfect crosses in polarized light. Only sections cut parallel to the bundles of plates (basal sections) show well the radiated structure; all other sections show this character less and less, depending upon the plane of the section, until it is transverse, when the mineral appears prismatic. The areas of spherocrystals are not infrequently bounded by overlapping six-sided plates, of which three are usually free; the others are intergrown and confounded in the central position of the aggregate.

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* Figure 4, section vi, Hitchcock's Green mountain gneiss, Geol. of Vt., vol. 1, 1861.

† The name Blue Ridge is given this mountain on the Rutland topographic sheet completed in 1891, but I have decided to use here the most commonly adopted local name.

The extreme mobility of the ottrelite-bearing solution is indicated by the manner in which the ottrelite needles have insinuated themselves into included feldspar grains along no visible lines of fissuring.

Mineralogic Constituents.—As in all described occurrences of this mineral, an abundance of inclusions exists. It is noticeable that, while quartz and occasionally feldspar are included, sericite, which is the principal micaceous constituent of the rock, is seldom enclosed by the growing ottrelite, but may be wholly or in part the nucleus about which an aggregate formed. Such nuclei seem in some cases to have governed the growth of the ottrelite. There was a tendency as the mineral formed for the plates to orient themselves parallel to the sericite nucleus, so that when such a nucleus is surrounded by basal ottrelite it is apt to be basal also. Whether this is another example of parallel growth or is accidental I cannot state definitely. By far the most abundant interpositions are a multitude of extremely minute black to brown dots and aggregates. With a number 7 objective these are resolved, in the main, into rutile, occurring in knee-shaped and heart-shaped twins, but generally in rounded forms, in which twinning is not distinguishable. In other cases the highest objectives are incapable of individualizing the grains, as is mentioned by Rénard.* In some crystals the rutile is grouped in reticulated lines conforming rather rudely to the planes of the two principal cleavages, but as a rule it is grouped along irregular lines that traverse the ottrelite and the groundmass alike. It may have been arranged originally in structural lines, developed along planes of bedding, that afterward were built into the ottrelite with total disregard of any observed relationship, in the same manner that quartz and feldspar droplets were built into albites in another phase of this rock. Other inclusions are graphite (determined by deflagration) and little coffee-brown ilmenite plates (titaneisen glimmer). A powerful current from an electro-magnet applied to that portion of the powdered rock which ran through a 120-mesh sieve attracted but a little of the particles, so that magnetite and probably ferrous oxide are absent. The usual test for titanium gave a positive reaction.

As in biotite and chlorite, pleochroic zones about crystals of zircon are very common in the ottrelite, and their characteristic dependence of maximum pleochroism upon the maximum pleochroism of the enclosing mineral is observable. While zircon usually occupies the centers of these zones, other zones occur having no perceptible associated inclusion.†

* Researches sur la Composition et la Structure des Phyllades Ardennes. Phyllade Ottrélitéfère de Monthermé. Bulletin du Musée D'Hist. Nat. de Belgique, vol, 3, 1884-85, p. 252.

† I am disposed to refer the brown material making these zones to minute rutile grains. Ottrelite containing such zones was subjected to the temperature of a Bunsen burner without destroying them, so they are probably of a mineralogic nature.

Although twinning with composition face parallel to 0 is not uncommon in the ottrelite, a large part of what seems to be twinning is seen to be due to overlapping plates. As the stage is revolved the wavy extinction caused by this may be observed,—the usual spherulitic structure.

Parallel Grouping of ottrelite Prisms.—Examples of crystal growth set up in several places at the same time occur in the rock where each part is controlled by every other, resulting in an irregularly outlined prism composed of many individuals separated by areas of the groundmass and yet all oriented together (see figure 1). This phenomenon is unlike that

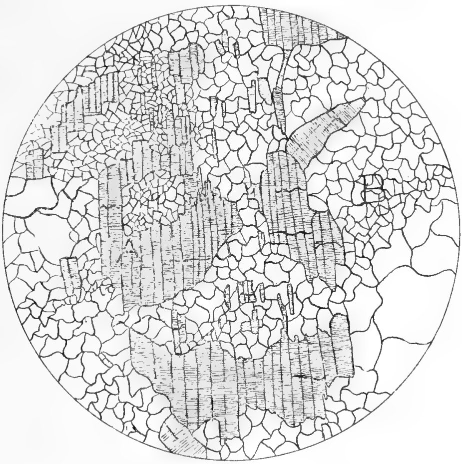

FIGURE 1.—*Thin Section of ottrelite Schist.* × 25.

Showing formation of ottrelite at many different points. Each small area is oriented with all the others, forming a large area showing a general prismatic outline. The prism has been developed transverse to the schistosity of the rock. The background is largely gneissic quartz, with some secondary feldspar. (Drawing from microphotograph.)

of andalusite, which occurs so frequently grown into large individuals, enwrapping all other minerals of the background, but is another example of independent parallel growth analogous to that of quartz in pegmatite, although in no way determined by the crystallographic position of the minerals of the groundmass. Such growths are commonly developed nearly at right angles to the layers of quartz and feldspar that make up the schistosity, and are usually freer from inclusions than the bundles. They occur between the main areas of ottrelite and may represent a

second generation. They were necessarily formed after the groundmass was converted to a mosaic by granulation.

Parallel grouping of rutile Grains.—The same phenomenon is noticed in the rutile. Little yellowish-brown grains of this mineral developed in the interspaces of the minerals composing the background tend, although made up of separate and sometimes isolated grains, to orient themselves parallel to one another, forming groups having prismatic outlines. These groups are only sparingly developed, but where observed they are generally parallel to one another* and to the schistosity of the rock, and are restricted in their occurrence, like the ottrelite individuals just described, to the most quartzose parts of the rock, which they enclose in the same manner as the ottrelite.

ALTERATION OF OTTRELITE INTO CHLORITE.

Relation of the two Minerals.—An interlamination of chlorite and ottrelite was mistaken at first glance for either the contemporaneous forma-

Figure 2.—*Thin Section of Ottrelite.* × 50.

Showing alteration of ottrelite to chlorite.—*A* = overlapping plates of ottrelite; *B* = bifurcating veins of chlorite allomorphosed after ottrelite and including cores of unaltered mineral; *C* = quartz and feldspar mosaic. (From a microphotograph.)

* Owing to the great single refraction of rutile, their minute size, and the fact that they seldom make the entire thickness of the section, it is difficult to detect the agreement or disagreement of their crystallographic position.

tion of these minerals or an infiltration of chlorite parallel to the basal cleavage of the ottrelite. Further investigation, however, showed that the chlorite as often traversed the ottrelite irregularly in bifurcating veins and enclosed parts of it (see figure 2). A study of the nature of these veins convinced me that the chlorite is an alteration product of the ottrelite. The edges of the veins where they traverse the ottrelite transverse to the basal cleavage are jagged, the saw-like teeth projecting along the composition faces or basal cleavage. The chlorite in such cases is distinctly made up of little fibers which have arranged themselves parallel to one another and to one set of twinning lamellæ. Lines of inclusion once continuous in the ottrelite now stop short against interlaminated areas of chlorite, showing the evident secondary nature of the latter mineral. In other places the chlorite is developed along the basal cleavage of the ottrelite, leaves this cleavage and follows one of the prismatic cleavages, and then again follows the basal cleavage, making one continuous line, thus producing steps, in much the same manner that garnet commonly undergoes this alteration.

Optical Characteristics.—Cores of unaltered ottrelite remain in the chlorite, and the pleochroic zones, once in the parent, are seen again in the secondary mineral, while the relationship of maximum pleochroism of these zones to the greatest pleochroism of the chlorite is handed down as well. This metasomatic phenomenon has not been observed in other phases of the ottrelite-bearing conglomerate thus far studied by me.

GROUNDMASS OF THE ROCK.

Mineralogic Constituents.—The background of the rock is composed of quartz and feldspar as principal constituents.

Feldspar.—The feldspar is fresh and glassy, untwinned, and is probably albite, but it is hardly abundant enough in the ottrelite bearing phases to make the rock a gneiss even in mineralogic composition; and, structurally, a gneissic habit has been nowhere observed where ottrelite exists to any extent.

Sericite.—Sericite is also abundant and occurs in minute prisms between the interlocking quartz grains and generally inclosed by the albite but rarely by the ottrelite. It also incloses lines of rutile dots arranged parallel to its cleavage planes, and next to the ottrelite it is the last formed mineral.

Anatase.—Associated with rutile in the groundmass are groups of stout and slender prisms and plates having a very high single and double refraction and a variable color, from brownish-yellow to blue, even in the same individual. These I identified as anatase, and for verification I

studied the sections described by Diller.* Unlike the anatase there described, its occurrence in narrow prisms in this rock, together with its rutile inclusions, seem exceptional. The stouter prisms have terminal faces of an octahedron and range in size from one-fiftieth to three-fiftieths of a millimeter in length. As the stage is revolved the pleochroism seems only the intensification of the inherent color of the mineral—browns becoming browner and blues becoming bluer. The presence of rutile inclusions shows the anatase to have formed after that mineral and suggests the probability of its being a paramorphic product of the rutile inclusions.

Rutile.—Rutile dots and prisms exist in multitudes inclosed by all other minerals of a secondary nature. They are so extremely minute that even in a very thin section they focus in six or more different planes.

In General.—All traces of original clastic material in the rock have disappeared; feldspar detritus, if it once occurred, has been converted into a mosaic of quartz, sericite, biotite and probably albite, and the detrital quartz has been granulated. The existing feldspar is the characteristic untwinned glassy variety carrying quartz and serecite inclusions so common throughout this horizon, and was formed after the granulation of the rock, since granulation could not have taken place without straining or crushing it. Nearly all the quartz is sprinkled with rutile inclusions, but it is noticeable that the larger areas have less of them and may be cores that have escaped granulation. Its presence, however, in such abundance militates against the probability of any of the quartz being allothegenic and indicates rather its secondary nature. In the same way quartz may inclose plates of micaceous ilmenite, but does not inclose sericite.

There is evidence of a second period of this crushing force indicated by a faint wavy extinction in the feldspar in some instances, and by the bending and breaking of ottrelite prisms.

ORDER OF CRYSTALLIZATION.

We have then in this rock ottrelite, chlorite, feldspar and quartz, and the three titanium-bearing minerals, ilmenite, rutile and anatase. What is their genetic order of development? This is a difficult question to answer without more data, and is particularly difficult in the cases of the ottrelite and rutile. The relative position of the former mineral can be determined easily, but the source of the solution introducing it is not readily discovered. Ottrelite was formed after the rock had undergone metasomatic and dynamic changes that converted its clastic feldspar into

*"Anatas als Umwandlungsprodukt von titanit im Biotitamphibolgranit der Troas." N. J. B. i, 1883, pp. 187–193.

its resulting minerals, after its detrital quartz was sugared and the rock had become a stable aggregation of minerals under the conditions of environment then existing. This environment changing, owing to one or more of the many factors affecting the character of a rock-mass, ottrelite was introduced probably, and it would seem necessarily, from some extraneous source. The environment of the rock underwent a third change, and this probably was an elevation, which strained the albites, fissured the ottrelite and subjected the rock to normal surface weathering, during which the conversion of ottrelite to chlorite was initiated. Prior to the granulation of the clastic constituents the titanium in some combination must have existed in the rock, but the mineralogic nature of this combination is obscure. The most probable source of rutile is from some titanium-bearing iron oxide, the presence of which has not been made out definitely, except in the case of micaceous ilmenite, itself manifestly of a secondary nature, occurring as it does in a clastic rock and which yields no evidence of alteration. Ordinary granular ilmenite, such as occurs so abundantly in phyllites, which is prone to decomposition, was most likely the common source for all three minerals carrying titanium, the rutile being an intermediate stage in the formation of anatase. The micaceous ilmenite was developed before the formation of the gneissic quartz, since the latter incloses it; the anatase probably forming after the quartz, as it occurs in the interstices between the quartz grains. If this be a correct interpretation, the order of crystallization of the existing minerals is essentially as follows: First, rutile and micaceous ilmenite, followed by the formation of gneissic quartz inclosing them, and coincidently the growth of sericite inclosing rutile. The glassy feldspars were next crystallized out, inclosing all the previously formed minerals, and the anatase may have resulted as an alteration product of rutile at about this stage in the rock's history. Then the ottrelite began its growth, including all the other minerals in the rock; and finally, the initial alteration of this mineral to chlorite closes the rock's history, as far as the ottrelite-bearing phase is concerned, up to the present time.

METAMORPHISM OF THE CLASTIC MATERIAL IN CONGLOMERATE PHASE.

Occurrence.—This conglomerate is stratigraphically equivalent to the schist above described, and the phenomena mentioned below occur in the rock from the town of Chittenden, between Chittenden village ("Slab City") and North Chittenden, where large outcrops occur along a divide on the western side of the direct highway between these villages.

Character of the Rock.—The rock macroscopically is a well-marked conglomerate in which metamorphism is shown by the crushing of quartz

and feldspar grains and by the development of serecite, muscovite, biotite and magnetite. These evidences of alteration are only incipient, so that the genuine clastic character of its principal constituents is undoubted. Quartz pebbles are most numerous and some attain dimensions sufficiently large to be dignified by the term bowlders, being 18 inches in maximum length, and make up nearly 90 per cent of the detrital material. Gneiss and feldspar pebbles are also common, pebbles of the latter in rare instances having dimensions of two by three inches. The groundmass is fine granular quartz, magnetite, plates of muscovite, and prisms of sericite. Under the microscope the evidence of the clastic nature of the rock is emphasized by the water-worn outlines of its pebbles and their parallel arrangement due to gravity.

Secondary Enlargement of clastic Tourmalines.—Thin sections of the conglomerate (numbers 699 and 700) were studied in detail and their descriptions are given later. The tourmalines occur in the rock as minute, stout crystals, bounded by crystalline faces developed independently of any apparent nucleus, and as imperfectly bounded areas of a secondary origin deposited upon clastic nuclei of the same mineral. Figure 1, plate 2, which is an instance of secondary enlargement of an original clastic grain, is given to show development of prismatic planes, and also two terminal faces of a rhombohedron imperfectly developed. The boundary of this nucleus is not perceptibly water-worn, but in other examples of this phenomenon the nuclei are distinctly pebbles of attrition, oriented with the other detrital constituents. The clastic tourmaline is colorless in transmitted light when the plane of the polarizer coincides with the extraordinary ray, and orange-yellow when the plane of the polarizer coincides with the ordinary ray. It gives in converging light one arm of a cross. The surrounding mineral is separated by a distinct line from the core and is much darker-colored, as might be expected from the isomorphous nature of the mineral. The pleochroism of the rim is from brown to nearly black, and there are corresponding differences in the intensity of the interference colors; the center polarizes in brilliant greens and reds, while the interference color of the rim is masked by the body color. The secondary tourmaline is perfectly oriented with the core, and parallels the secondary enlargements of quartz grains described by Irving and Van Hise* in this respect. There are abundant inclusions of iron oxide (possibly ilmenite) and some quartz in the secondary part, but the core is free from them. They are particularly numerous about the sides of the angular core and along the basal portion of the enlargement. Two corners of the latter have inclusions of pale-green sericite prisms projecting into the groundmass, showing the

* Bulletin No. 8, U. S. Geol. Survey, 1884.

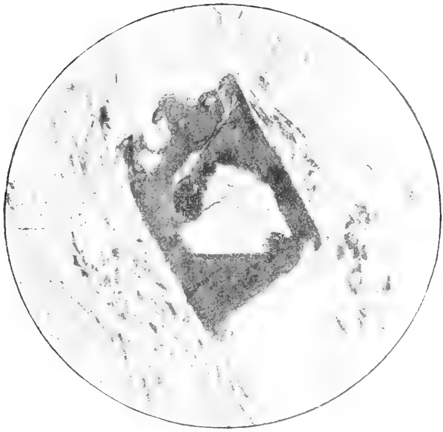

Figure 1.

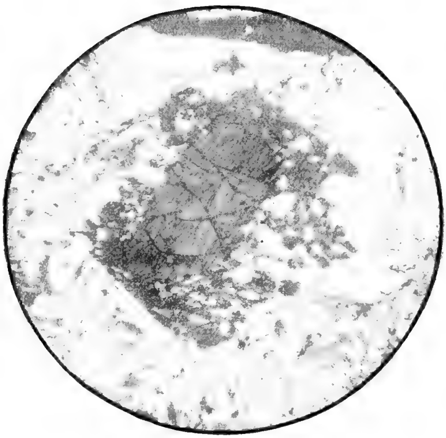

Figure 2.

SECONDARY ENLARGEMENT OF CLASTIC TOURMALINE.

formation of tourmaline after the dynamic sericite, and also after the iron products resulting from the decomposition of some iron-bearing silicate or oxide. In ordinary light these prisms are seen to traverse the tourmaline diagonally and they are certainly included. With a lens the tourmaline can be seen to make the entire thickness of the section.

Another example of secondary enlargement has the allothegenic core distinctly water-worn and oriented physically with the other clastics in the section and optically with the authogenic addition (see figure 3). The enlargement has nearly complete crystallographic boundaries—a prism doubly terminated; one end has the planes of a rhombohedron,

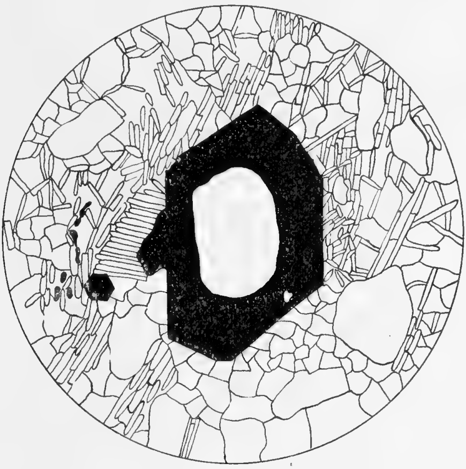

FIGURE 3.—*Thin Section of water-worn tourmaline Pebble.*

Showing secondary growth bounded by nearly complete crystallographic faces. (Drawing from a microphotograph.)

the other having these and a small basal plane. In this the detrital core is basal, giving a well-marked uniaxial cross of a negative character; it is of an orange-yellow color and free from interpositions. Owing to its great depth of color, the enveloping tourmaline transmits light only along its edges. Its crystal-faced outline is occasionally interrupted by penetrating grains of quartz, and some grains may be entirely enclosed.

A third example shows the dark-colored, secondary mineral penetrating the clastic core nearly to its center along fissures formed prior to this secondary growth. The contrast between the two parts is very distinct,

the center having a pale blue to pale orange color in transmitted light, although composed of but one individual, and is free from inclusions, while the outer part is very dark and thickly sprinkled with grains of gneissic quartz.

Still a fourth example (see plate 2, figure 2) has a dark core, with a still darker rim, appearing as a network of bifurcating arms surrounding the grains of the quartz and feldspar mosaic and on one side penetrating irregularly along cleavage lines into and enclosing parts of a clastic area of plagioclase. Gaseous emanations or solutions carrying boracic acid are well known to possess the power of attacking other minerals and producing new ones, and the action of the tourmaline-bearing agent, whatever it may have been, seems to be another instance of the same phenomenon, for the clastic plagioclase is attacked and the minute prisms of sericite which had been developed in it along cleavage lines have been dissolved by the growing mineral. Secondary glassy feldspars are included in the tourmaline and reveal no evidence of having been attacked, but sericite seems generally to have been absorbed. The clastic plagioclase is optically a unit with tourmaline ramifying through it; hence the latter must have eaten its way, excepting along cleavage lines, rather than to have penetrated the feldspar along lines produced by its granulation under pressure. Quartz does not seem to have been attacked, and one prism of biotite has been built into the secondary mineral.

Numerous cracks traverse the core, most of which abut abruptly against the authogenic part, and, although fissures and irregular cracks may traverse the outer portion, they are usually limited to the ends of the prism and do not traverse the core.

All the detrital tourmaline is macroscopically visible in the sections studied; nearly all are of an exceptional orange-yellow color, suggesting a common source, and in size they vary from that of a pin-head up to an eighth of an inch.

It has been difficult to ascertain the source of the material forming this conglomerate horizon in Vermont, and it is hoped that a microscopic study of the terranes below may result in the discovery of this tourmaline *in situ* and furnish a basis for further evidence.

Two Periods of Disturbance indicated.—Two periods of dynamic action are further indicated (see page 154) by the phenomena connected with the tourmaline. Before the deposition of the allothegenic cores there was a period of dynamic action, during which some of the detrital feldspar material was converted into an interlocking mass of quartz, biotite, sericite and probably albite. Part of the quartz was comminuted, and the fissures were produced in the tourmaline clastics. After this action had ceased and the secondary tourmaline had been formed, a second

crushing took place, much less intense than the first, indicated by the breaking and faulting of tourmaline prisms and the fissuring of the new tourmaline mentioned above. This second crushing is probably to be correlated with that which broke the ottrelite prisms in the ottrelite schist.

Alteration of clastic Feldspars.—The alteration of detrital feldspars, principally microcline, to quartz, sericite, biotite and albite is well shown. This change takes place about the edges of the grains, along cleavage planes emphasized by pressure, and along irregular cracks. Lines of inclusions in the clastic quartz serve to separate it from that resulting from the alteration of feldspar, the latter being always clear and glassy. These are commonly liquid-filled cavities with characteristic gyrating bubbles of carbonate dioxide, but in both the clastic microcline and secondary albite they are even more plentifully distributed. Liquid cavities in the quartz may have, besides the bubble, a single prism of some indeterminable doubly refracting mineral or an apparent cube, which, however, is also doubly refracting.

One of the thin sections (number 699) has a large pebble of microcline, three-fourths of an inch long, which retains its original water-worn outline, excepting at its ends, where it is partially crushed. Lines of sericite, biotite and quartz traverse it regularly along emphasized cleavage planes and irregularly about grains resulting from granulation. Thousands of minute dots of hematite or limonite are distributed through it, and there is a tendency for them to be arranged in lines normal to the basal cleavage of the feldspar. It is these that give the flesh color to the mineral in the hand specimen. Other interpositions are numerous rhombs of siderite, exhibiting all stages between the pure mineral and its pseudomorphous resultant, limonite. These or their limonite representatives occur throughout the rock, but they are noticeably more abundant in the clastic feldspars. Their distribution indicates their formation after the feldspar was deposited in the rock, and if this be the case, there were two periods of alteration of the microcline—one during which siderite or some iron-bearing carbonate was a stable alteration product under the conditions of environment, and a second during which the carbonate itself changed to limonite, not contemporaneously with the development of sericite, but posterior to that change and probably after the rock came under the operation of surface disintegrating influences.

Sericite in minute hexagonal plates and prisms terminated by basal planes are scattered through it and seem to have resulted from a direct alteration of the feldspar without the aid of its introduction in solutions from other parts of the rock. Liquid cavities are not nearly so numerous as in the secondary feldspars.

The interdependence of the different phases assumed by minerals,

upon all the varied factors going to make up their complex environment' and the correlation of these phases offer, it seems to me, one of the most interesting fields of research to be found in the petrographic and chemical history of a rock.

Clearing Action of growing Sericite.—Surrounding the pebble and along lines traversing it, as well as about crystals of siderite, there are conformable zones of microcline free from inclusions of iron products. These are associated with the development of siderite and sericite, and, wherever lines of movement in the latter mineral traverse microcline or plagioclase pebbles carrying interpositions, on either side of them there are

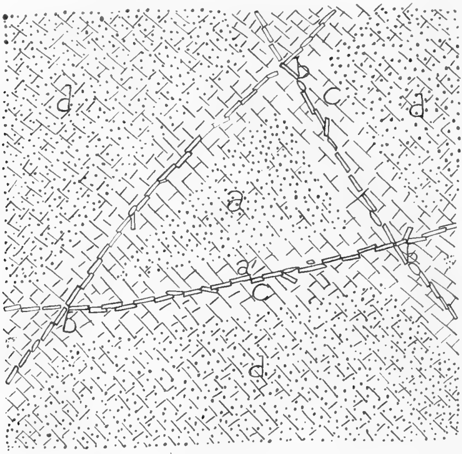

FIGURE 4.—*Thin Section of microcline Pebble.*

Showing clearing action of sericite. (Drawing from a microphotograph.)

parallel belts from which they have been removed. The border zone of the pebble has its folia of sericite running parallel to it. As the sericite grew as a product of dynamic metamorphism, it acted like a sponge, removing the inclusions and forcing the iron into a new combination, probably biotite. Figure 4 represents a triangular area of microcline illustrating this. In the central part there is an area, *a*, carrying the usual number of inclusions. Outside of this there is a zone, *a′*, free from iron inclusions; then there is a parallel line of sericite prisms, *b*, outside of which there is another parallel zone, *c*, also free from inclusions, and this is surrounded by the mass of the pebble *d*. The correspondence of

the optical orientation, even to the minutest twinned lamellæ, is identical on either side of the line of sericite, and the feldspar appears very fresh as compared with that not thus cleared of its inclusions. Its polarization colors are much more uniform in the cleared areas, and the greater the amount of the impurities and the more unequal their distribution, the greater the variety of mottled, tinted colors under crossed nicols. In case there are two lines of sericite close together, the interspace may be entirely cleared (see a', figure 5).

In attempting to interpret correctly the cause of the outer clear rim about feldspar pebbles only two hypotheses need be considered—it is either secondarily deposited feldspar or is produced by some subsequent action that eliminated the interpositions. If secondary, then the outlines of the feldspar areas having inclusions are too jagged, and concave surfaces are too common to have been the result of ordinary attrition, while the possibility that the new feldspar was added so as to change their outline to that of normal pebbles is very improbable. In the case of the largest pebble in the section glassy feldspar accompanied by sericite folia follows the outer part of the pebble for a distance, then penetrate into the interior, following lines of sericite. Bordering areas of the background not containing sericite have no complementary clear zone in the feldspar. Interior lines of sericite and their accompanying dependent zones are only explainable in one way. To assume that they are secondary growths necessitates the subsequent displacement of the feldspar clastic a distance equal to the cleared areas and a consequent probable displacement of its optical continuity. As a matter of fact, all parts extinguish as a unit, the conformity of the positions of the twinning lamellæ on either side of the serecite indicating their original crystallographic and optical continuity. Examples of apparent secondary enlargements of clastic feldspar are becoming so commonly described that it may be well in the future to bear in mind this phenomenon, which simulates so closely that of genuine enlargement and which may have led to misinterpretations in the past.

Alteration of clastic Microcline into Plagioclase.—In connection with the study of secondary feldspars in metamorphic rocks, it is interesting to note the trend of certain phenomena observable in the granulated end of this large pebble mentioned above where secondary albite and clastic microcline are intermingled. Dr Wolff has lately called attention to a possible relationship between detrital areas of feldspar and secondary albites,* and the facts here observed substantiate his interrogative hypothesis. With but very few exceptions in the Vermont rocks studied by me have I noticed secondary feldspars free from inclusions of seri-

*Metamorphism of Clastic Feldspar in Conglomerate Schist: Bull. Mus. Comp. Zool., vol. xvi, no. 10, p. 183.

cite and quartz. These minerals may be distributed throughout the feldspar, but there is a marked tendency for them to occur in groups in the central part, and the outline of groups is rudely conformable to that of the inclosing mineral. An explanation of this phenomenon has never been offered that appears entirely satisfactory. It seems, however, that we must be on the right track if we remember that the minerals, quartz, sericite, biotite and plagioclase, are the commonly recognized products of the decomposition of feldspar that has been subjected to the influence of dynamic forces, while at the same time the presence of quartz, sericite and albite making the groundmass of the rock would be referred at once to such an origin by all who are familiar with the ordinary microscopic phenomena observable in metamorphosed sedimentary rocks. Many feldspars (see those described below from East Clarendon, Vermont) have interpositions of all other minerals occurring in the rock, but the history of their immediate origin and growth is not the same as for those under present consideration.

Figure 5 is taken from the granulated portion of the above-mentioned feldspar and exhibits diagrammatically an area under the microscope covered by a number 5 objective: *a* is a portion of the normal microcline pebble filled with inclusions; a^1, the same, with its interpositions removed by the development of dynamic sericite, *i i* and *h h*; a^2, areas of clastic microcline included in secondary plagioclase, *c*; and *b* are minute prisms of serecite grouped in the plagioclases, but impinging against the microcline on one side in the upper area.

At *d* are cleavage lines, emphasized by strain, showing abrupt disappearance of inclusions along a line corresponding in direction to the basal cleavage in the microcline *h h* and *i i*; *e*, rhombs of limonite pseudomorphs after siderite; *g*, small liquid cavities arranged in lines parallel to lines of hematite inclusions in the feldspar generally; *o*, faint traces of the double twinning of microcline occurring in the plagioclase. Two facts in particular are intended to be brought out: First, the grouping of sericite prisms in the center of the lower plagioclase and their contact with the clastic feldspar in the upper; second, the occurrence of isolated areas of microcline in the plagioclase a^2 and the conclusions to be drawn therefrom. The plagioclase is known to be secondary, as it occupies areas in and includes portions of granulated microcline once continuous. Sericite is developed along the lines *h h* and *i i*, which are cleavage partings. The linear area of microcline, a^2, which is isolated, is optically oriented with a^1 and has been separated from its parent along the basal cleavage. Plagioclase surrounds and traverses it, dividing it into isolated areas, but all oriented with one another. It seems to me that this is a case of plagioclase forming about and from an area of microcline. The evidence in favor of this is complete if all the data in the upper plagioclase are taken

into consideration. The linear distribution of the microcline inclusion and its optical relation with *a* are such that it manifestly was once a part of the feldspar pebble. It is improbable that it could have been moved in separate pieces from the line *i i* without having its crystallographic and optic orientation disturbed. The twinning lamellæ of the several parts correspond with one another and with those in a^1, while the extinction of *c* is not in parallelism with either set of twinned lamellæ in a^2. The plagioclase *c*, resulting from the alteration of the microcline,

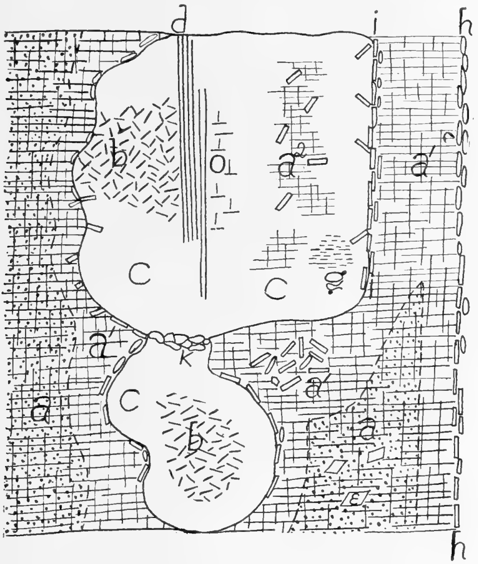

FIGURE 5.—*Thin Section of microcline Pebble.*

Showing alteration of clastic microcline to plagioclase.

ramifies through a^2, apparently absorbing it, and at the same time causing the development of sericite about and in it. This will be alluded to again when the areas of sericite *b* are considered. The arrangement of the fluid cavities g^1 in lines parallel to the lines of hematite inclusions in the microcline does not seem to be accidental, but seems rather to indicate the operation of a grinding influence of the inclusions as the new feldspar formed and absorbed the old. Cleavage lines *d*, which are parallel to *i i*, also seem to be connected in some way with the cleavage in

the pebble, as though the plagioclase, as it replaced the microcline, took on a crystallographic position, controlled by old planes in the latter that had been emphasized by dynamic movements, in which one cleavage is parallel to *P* or *M* in the microcline. Along these cleavage lines, at *o*, there are faint indications of twinning, after the albite and pericline laws. Plagioclase may have replaced old microcline twinning lamellæ, itself twinning after the same law, so that we may have the original twinning of the microcline handed down to its alteration product, plagioclase. The upper group of sericite inclusions, *b*, stops short in a plane against these cleavage lines, extends across the plagioclase to the left, and impinges against the microcline, which at this point is not crushed or strained, while the feldspar on all other sides of the upper area is granulated. Does not the area defined by these inclusions represent original microcline, now replaced by plagioclase, the *k* going into the sericite?

So complex have been the conditions of environment that it is very difficult to interpret correctly, if at all, many phenomena exhibited in metamorphosed rocks, but in this case it seems to be legitimate to suppose that for a time the conditions were such that, as the plagioclase formed from the microcline, sericite was developed. Afterwards the introduction of new factors began. Sericite was no longer developed, while plagioclase continued to form both from the microcline and by addition from other parts of the rock, the growth taking place in all directions excepting where the area of inclusions abuts against the microcline which had escaped granulation. Where this growth took place uniformly in all directions the inclusions are seen to occupy a central group in the plagioclase as in the lower area. The linear area of microcline, a^2, with its associated sericite prisms, is an intermediate stage between original clastic feldspar and the completed change *b*.

In this connection Dr Wolff remarks:

> "It does not seem possible to explain all these cases of mere outward growth of the feldspar grains by addition of fresh feldspar of the same species to the core, but rather by an actual replacement of the detrital core by the feldspar of the enlargement."*

Strongly contrasted as to immediate origin are the secondary feldspars found in another phase of this conglomerate horizon and those occurring in a phyllite in Massachusetts.

CHLORITE SCHIST AND PHYLLITE.

Their Plications built into secondary Albites.—The differences in the environment of growing secondary feldspars and their consequent histories are seen when the above case is compared with the porphyritic feldspars

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* Metamorphism of Clastic Feldspar in Conglomerate Schist: Bull. Mus. Comp. Zool., vol. xvi, no. 10, p. 182.

occurring in the chlorite schist found at East Clarendon, Vermont, and the phyllites of Greylock mountain, situated southwest of North Adams, Massachusetts. In the occurrence at the first-named locality the feldspar (albite), which occurs as single individuals or simple twins, a fourth of an inch across, was formed after the rock had been metamorphosed from an original shale to a chlorite schist and mountain-making forces had rearranged the minerals composing the rock into minute crenulations.

Composition of the Groundmass.—The groundmass of the schist is composed of granular, gneissic quartz and feldspar, much sericite and chlorite marking its foliation, as essential constituents, and as accidental minerals there are innumerable rutile dots and prisms, prisms of tourmaline and little black plates, probably ilmenite. All these, including the minute plications of the schist, have been built into the albite as it grew. Quartz droplets are arranged in sharp serratures, the continuation of the corrugated lines outside the crystals; but the sericite and chlorite, particularly the former mineral, seem to have been eliminated by the growing albite forcing them to one side or by the chemical solution which deposited the feldspar attacking and dissolving them. The chlorite is occasionally included; the sericite rarely. Rutile, ilmenite and tourmaline are also enclosed. In detail the outlines of the crystals are very jagged, the feldspar projecting in tongues into the background along the schistosity; but, considered as a whole, they are well-defined prisms. The colorless inclusions are by no means limited to quartz, for many give imperfect hyperbolæ and are secondary feldspars of a younger generation. Nothing now remains in the rock that can be said to be of clastic origin, and certainly after the rock had been converted into a chlorite schist and crenulated, as we find it to-day, no detrital feldspar could have been left to serve as nuclei or furnish material for the large, last-formed porphyritic albites. Solutions with the necessary elements must have been derived from some extraneous source.

The occurrence of the albites in the Greylock phyllites collected by Dale and described by Wolff* have much the same history, only secondary albites there have been enlarged by a tertiary growth of the same mineral.

The fissuring and occasional faulting of the large albites from East Clarendon is to be correlated with the faulting of the secondary tourmalines and ottrelite prisms above described and indicate a second period of mountain-building forces.

My thanks are due to Dr Wolff, who has given me many valuable suggestions during the preparation of this paper.

* Ibid., p. 183.

CAMBRIDGE, MASS., *March, 1892.*

Explanation of Plate 2.

Secondary Enlargement of clastic Tourmaline.

Figure 1.—Secondary enlargement of clastic tourmaline pebble, showing prismatic planes and slight development of terminal planes. Partially included sericite prisms and occasional inclusions of quartz grains in new growth.

Figure 2.—Secondary enlargement of clastic tourmaline. The core is free from interpositions; the secondary mineral has abundant inclusions of gneissic quartz aud feldspar. Many of the fissures of the core abut abruptly against the new mineral, showing two periods of straining. The growing tourmaline is seen to have attacked a clastic area of plagioclase, penetrating it irregularly and absorbing sericite previously developed along cleavage lines.

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PHASES IN THE METAMORPHISM OF THE SCHISTS OF SOUTHERN BERKSHIRE*

BY WILLIAM H. HOBBS

(*Read before the Society August 16, 1892*)

CONTENTS

INTRODUCTION.

Beds represented within the Area.—In southwestern Berkshire county, Massachusetts, and in northwestern Litchfield county, Connecticut, is an area in which non-calcareous schistose rocks alternate with limestones which are in part micaceous, dolomitic, graphitic, pyroxenic, tremolitic or quartzitic.† Though the schists are the "mountain rock," they are found in the valleys as well and are frequently inclosed as islands in

* Published with the permission of the Director of the United States Geological Survey.

† The area has been described and mapped by Professor J. D. Dana: On Taconic Rocks and Stratigraphy, with a Geological Map of the Taconic Region. Am. Jour. Sci., 3d ser., vol. xxix, pp. 205–222, pp. 437–443, pl. ii.

the limestone. The rocks here described occur in portions of the townships of Egremont, Sheffield and Mount Washington, in Massachusetts, and of Canaan and Salisbury, in Connecticut. They have been studied areally and structurally in the field and petrographically in the laboratory. The full report of the investigation will appear elsewhere.*

The area includes three beds of schist separated by beds of limestone, besides the thin layers of the former which are sometimes found within the limestones near the contact. The lowest of these schist beds is associated with quartzite and gneiss, and is more lacking in uniformity of character than the others. It incloses numerous veins of coarse pegmatite and is specially rich in tourmaline, though this mineral is also found in the two other horizons.

The next younger schist is separated from the one just mentioned by a dolomite, which is always very crystalline, and at many localities contains white pyroxene, tremolite or phlogopite. It moreover contains layers of graphitic rock and of canaanite.† The schist horizon itself is quite variable in character, but is frequently distinguished by the occurrence of macroscopic garnets and staurolite.

The upper schist bed is separated from the last mentioned by a limestone in which neither sahlite, tremolite nor canaanite has been found. The schist itself is free from the macroscopic garnets and staurolite characteristic of the central bed. In common with both the other beds, it contains porphyritic crystals of feldspar, but here they seem more generally to have glistening cleavage surfaces. Especially in the Mount Washington area this bed shows facies that are quite sericitic or chloritic, the latter with magnetite often in octahedra as big as a pea. Ottrelite, though not restricted to this horizon, is more frequently found here than in either of the others. Though the rocks of the three non-calcareous beds have a preponderance of feldspar, they are structurally schists and they are so designated, as it is convenient to distinguish them from typical gneisses in adjacent territory. Notwithstanding characteristic differences can be pointed out, serving to distinguish the three beds when regarded as units, individual hand specimens from each often show resemblances more striking, so that it is generally impossible to refer a specimen to a definite bed on the basis of petrographic character only.

Evidences of orographic Disturbances.—Typically metamorphic minerals abound in all beds, but especially in the central schist bed and the dolomite underlying it. The beds have been thrown into sharp folds, most frequently reversed, with resulting shear planes and secondary foliation at many localities.

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*The work here referred to forms part of an investigation conducted by Professor Raphael Pumpelly for the United States Geological Survey.

† American Geologist, vol. xv, 1892, p. 45.

Porphyritic Minerals of the Schists resulting from metamorphic Action.

The Minerals and their Association.—It is my object in this paper especially to describe the so-called porphyritic constituents of the schists that have been developed or modified by metamorphic agencies. Under this head are included feldspar (largely an acid plagioclase), garnet, staurolite, tourmaline, biotite and ottrelite. Other constituents present in greater or less quantity are sericite, quartz, graphite, chlorite, magnetite, ilmenite, pyrite, fibrolite, calcite, rutile, sphene (and leucoxene), zircon and apatite. In nearly all specimens there is a matrix made up of varying amounts of feldspar, quartz and a micaceous mineral, which is in some cases a silvery mica (sericite); in other instances sericite with biotite or chlorite. Associated with these minerals are accessory graphite, ore material, etc. Almost without exception porphyritic feldspars occur in the matrix, usually many times larger than the feldspar grains composing it.* In addition to the modifications of the rock arising from the micaceous constituents present, petrographic variations consist mainly in the character of the porphyritic feldspar and in the presence or absence of the other porphyritic constituents, viz: garnet, staurolite, tourmaline, biotite and ottrelite. The central schist bed has furnished most of the specimens in which the structures I shall describe were observed, though such structures do not seem in all cases to be restricted to that bed.

Porphyritic Feldspar.—The porphyritic feldspars appear under a number of modifications. In certain facies of the rock they are more or less oval in shape and inclose with more or less uniformity blades of sericite, particles of graphite, ore material or tourmaline. They are commonly either simple individuals or simple twins. They quite resemble in sections the beautiful photomicrograph which is figure 8 of the paper by Wolff on "The Metamorphism of Clastic Feldspar in Conglomerate Schist."† Though these feldspars may show no marked evidences of strain, many instances of polysynthetic twinning have been observed, and the occasional localization of the lamellæ about cracks in the individual would indicate that the twinning is the result of internal mechanical movement. The twin lamellæ allow of the determination of the feldspar as an acid plagioclase.

Dynamic metamorphism has at other localities been more intense, as evidenced in sections where the granulation of the feldspars may be

*See descriptions of similar feldspars in the schistose and conglomeratic rocks of Hoosac mountain and elsewhere. (Pumpelly: The Relation of Secular Rock-Disintegration to Certain Transitional Crystalline Schists. Bull. Geol. Soc. Am., vol. ii, 1891, pp 209–224. Wolff: Metamorphism of Clastic Feldspar in Conglomerate Schist. Bull. Mus. Comp. Zool., vol. xvi, 1891, pp. 173–183, pls. i–ii.)

† Bull. Mus. Comp. Zool., vol. xvi, 1891, pp. 173–183, pls. i–ii.

seen. This may be largely peripheral, as in a specimen (number 3230)* from near Ore Hill, or it may include nearly the entire crystal, as in a number of thin sections (number 3224) from Miles mountain. Such pronounced granulation seems, however, to be most developed in the vicinity of shear planes, and is accompanied by a stretching and tearing of the other constituents. Figure 1, *A* shows the effect of this action on two adjacent garnets (number 3230).

Granophyre Structure in Feldspar.—Those structures which I desire here more especially to emphasize, however, seem to be found farther removed from shear planes, and concern phases of metamorphism where mechanical movement has been a minimum. In such localities the feldspars have frequently a mottled appearance, like *D* in figure 1 (numbers 3111, 3326, 3328, 3463).

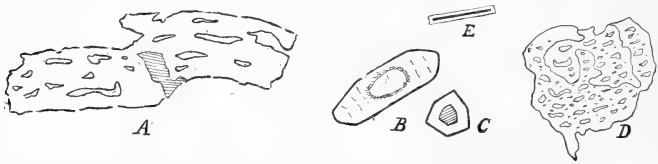

FIGURE 1.—*Examples of Deformation and modified Growths of Minerals in Schists.*

A = stretched garnets. *B* = secondary growth of tourmaline; the oval core has brown tones, the enlargement blue or plum tones; the cloudy material near the junction is probably graphite. *C* = zonal structure in tourmaline. *D* = mottled feldspar. *E* = parallel growth of ilmenite and chlorite.

The included areas sometimes take the form of curving canals, at others polygonal outlines, and, in short, exhibit all the peculiarities of the micropegmatite or granophyre structure. Hexagonal outlines characterize many of the areas, and there can be little doubt that they are in these cases quartz (number 3463).

The inclosed quartz extinguishes alike over considerable areas, but sometimes shows several orientations within a single crystal of feldspar.† The feldspars which show this structure exhibit in many cases the minimum of crushing and but little effect of stress, while in other cases the granophyre structure coëxists with a pronounced granulation and exhibition of secondary twinning. In the latter case the structure is very complicated, and it is difficult to distinguish the secondary quartz from the mosaic of feldspar. It was frequently observed (in those cases where but little deformation could be made out) that the granophyre occupies the center of a crystal, leaving a clear rim.

* The numbers of sections are those of the United States Geological Survey collection.

† Cf. Iddings, Obsidian Cliff, Yellowstone National Park: Seventh Ann. Rep. U. S. Geol. Sur., 1888, p. 275, plate xv, fig. 5.

Its Origin.—The question of the origin of the granophyre in these doubtless clastic rocks is a difficult one. It is a question that deserves further study, and I hope later to be able to throw a little more light on the problem. For the present it can be said that the relation of the intergrown quartz to the quartz outside, as exhibited in a number of sections, lends no support to the view that the granophyre structure has been preserved from some detrital grains which have an igneous origin, but that it is of a secondary nature, being developed in the already formed rock. The usual interpretation of granophyre structure to indicate an igneous origin for the rock in which it occurs is no longer tenable. Irving in 1883* described micropegmatite in a number of granitic porphyries and augite syenites from Lake Superior, the secondary nature of which was evident from its quartz being oriented like the areas of secondary quartz lying without the feldspars. Somewhat similar cases have been described by Judd.† In a recent memoir by Julius Romberg‡ on the petrographic characters of an extensive series of Argentine granites the granophyric structures are described in much detail with the aid of beautiful plates. The author raises the question of their secondary origin through weathering, and adduces many facts which make it probable that this is their origin.

In some of the feldspars which show the mottled structure in the rocks now under consideration it can be determined that the inclosed areas are feldspar of a somewhat different composition (microperthite structure). This is particularly well shown in the instance of a feldspar core having a rim which polarizes yellow, the core polarizing gray. A set of mottlings in the core give the same yellow tint as the rim and extinguish with it. This would seem to show that the original feldspar core had been partially replaced by a feldspar of different composition, which composes the rim entire. This view is quite in harmony with Wolff's deductions concerning the feldspars in the conglomerate schist of Hoosac mountain.||

Secondary Enlargements of Feldspar.—Secondary enlargements of feldspar seem to be quite common in the rocks under investigation, and they have been found at localities widely separated.§ Occasionally these en-

*The Copper-bearing Rocks of Lake Superior: Monograph V, U. S. Geol. Survey, 1883, p. 114, plates xiv, xv.

† On the Growth of Crystals in Igneous Rocks after their Consolidation: Quart. Journ. Geol. Soc. vol. xlv, 1889, pp. 175–186. pl. vii. Ibid., vol. xlii, 1886, p. 72.

‡ Romberg, Petrographische Untersuchungen an argentinischen Graniten, mit besonderer Berücksichtigung ihrer Structur und der Entstehung derselben: Neues Jahrbuch f. Mineralogie, etc., Beilage-Band viii, 1892, pp. 314–323, 374–378, plates ix–xii.

|| Loc. cit. See also Lehmann, Jahresbericht der Schlesischen Gesellschaft für Vaterländische Cultur, 1886, pp. 119–120.

§ Thorpe mountain (numbers 3574, 3476 and 3477); northeastern slope of Mount Washington, (number 2129); southeastern slope of Mount Washington (number 3104); Miles mountain (number 3213½), and near Rattlesnake hill (number 3030).

largements are visible under a lens, owing to the unequal distribution of graphite (number 3574). The commonest case of enlargement is that in which there is but one secondary growth visible (figure 2, *B*, *C*, *D*). The original growth shows crystal boundaries and is sharply outlined against the enlargement, which has generally an irregular boundary and contains more sericite, interpositions of ore, etc. The enlargement is generally at least of a more basic feldspar than the core, as shown by the extinction angles. In the growths figured, *B* is evidently cut near the brachypinacoid and *C* probably near the base, as in this latter instance the extinction angles are nearly the same and closely parallel to the long side. It is thus probable that both feldspars are intermediate in composition between oligoclase and andesine. In *D* is represented an unusual growth, of which the core is simply twinned, though the enlargement is not (see plate 3, figure 2, *A*). In the same section is another growth in which core and rim are twinned alike. I have noticed some-

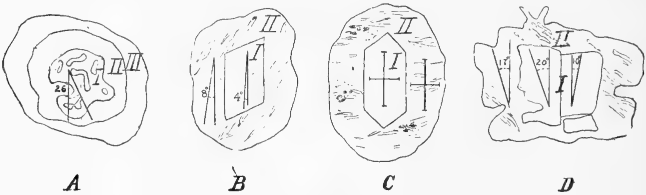

FIGURE 2.—*Secondary Enlargements of Plagioclase.*

A, *B*, *C* and *D* are examples of secondary enlargements of plagioclase which occur in the schist of Mount Washington, near Joyceville (number 3104). *I* is the core in each case; *II* and *III* are the enlargements. *A* = rounded mottled core with two enlargements; *B C* = examples of core with crystal boundaries; *D* = unusual instance of twinned core surrounded by an untwinned enlargement.

what analogous cases in the growths of epidote around allanite from the porphyritic granite of Ilchester, Maryland,* the core of allanite being twinned, though the encircling oriented epidote is a single individual. In the gneiss of Warner mountain, east of Sheffield, Massachusetts, such growths occur, and here the epidote has been observed twinned like the allanite in one instance, and in another the allanite core is twinned and the epidote untwinned. Van Hise† has figured a grain of feldspar with an enlargement, and both are twinned alike. Wolff states that in the enlarged feldspars of the conglomerate schists of Hoosac and Bear mountains, twins are sometimes common to both core and rim, but also are found only in the core.‡ Judd || describes and figures an enlargement of

* Am. Journ. Sci., 3d ser., vol. xxxviii 1889, pp. 223–228, figs. 1 and 2.

† Bull. no. 8, U. S. Geol. Survey, pt. ii; also Am. Journ. Sci. 3d ser., vol. xxvii, 1884, p. 399.

‡ Loc. cit., p. 182.

|| Quart. Journ. Geol. Soc., xlv, p. 186, pl. vii, figs. 1 and 2.

feldspar in the "labradorite andésite" of the isle of Mull, in which the twins of the core are prolonged as twins in a more acid feldspar.

An enlargement where the core is unmottled but has a rounded outline is seen at *A* of figure 1, plate 1. In figure 2, *A*, there is exhibited a somewhat different modification. In this instance, as in some others, the core is mottled and of irregular outline. Two enlargements are indicated by the different extinction angles (Cf. also plate 1, figure 1, *B*). Second enlargements have been found also at other localities (numbers 3213½ and 3115). In a specimen from near Jug End, Mount Washington (number 3139) there seem to be several zones of growth in feldspar.*

Their Origin.—The fact that the cores of many of the growths which have been described have crystal boundaries makes it extremely improbable that they can be of detrital origin, though the rocks themselves are undoubtedly clastic. The most probable view of their origin, it seems to me, would regard them as a metamorphic product due to the recrystallization of the detrital grains of the rock, as in the better-known cases of garnet and staurolite.†

Garnet and its secondary Enlargements.—As already stated, this mineral when in macroscopic crystals is specially characteristic of the central schist bed. It is the common dark red, nearly opaque variety, and occurs in rhombic dodecahedra with truncations by the icosatetrahedron. The crystals vary in size from those that are microscopic to those a centimeter or two in diameter. Frequently, though not always, they are associated with staurolite. They exhibit the usual characters on microscopic examination. They have a decided pink absorption and are sometimes compact, though often ragged in appearance from the inclosure of the constituents of the matrix. Minute hair-like interpositions, which are very abundant, are with much probability rutile. In the schist of Johnny's mountain, near Sheffield (number 3114) interesting secondary enlargements of the garnet have been observed. The core or first growth is pink and comparatively free from inclusions, with the exception of the hair-like interpositions above referred to. The rim of secondary enlargement, making from one-half to two-thirds the area of the entire growth, is nearly colorless, and near its junction with the core is filled with an aggregation of cloudy ore material, probably magnetite. Where several crystals have formed in a continuous aggregate, the enlargement incloses the aggregate, just as in other cases it incloses an individual (figure 3, *A*).

* Cf. Judd, loc. cit., plate vii, fig. 3.

† For the literature of secondary feldspar enlargements in rocks of eruptive origin see:—

Haworth, A Contribution to the Archean Geology of Missouri; Inaug. Dissertation, Johns Hopkins University; also printed in American Geologist, May and June, 1888.

Judd, Quart. Journ. Geol. Soc., xlv, 1889, pp. 175–186.

Romberg, Neues Jahrbuch für Mineralogie, etc., Beilage-Band viii, 1892, p. 304, plate xv, fig. 54.

In one instance stains of iron oxide were observed to traverse the enlargement and stop abruptly at its junctions with the core (figure 3, *B*).

Staurolite.—This mineral has only been found in the central schist bed. It is usually macroscopic and its crystals sometimes attain to a length of two or three centimeters. They are bounded by the usual forms, and are frequently twinned in inclined crosses. The color is usually black, but is sometimes cinnamon-brown. Under the microscope the mineral presents the usual characters with strong pleochroism. Like the garnet, it is sometimes compact, sometimes very ragged, from inclosures of the matrix. Secondary enlargements have not been determined, but the observation of crystals with an outer zone which, unlike the center, is free from inclusions, makes their occurrence not improbable.

FIGURE 3.—*Garnets with secondary Enlargements.*

From schist of Johnny's mountain, near Sheffield.

Reactionary Rims of Staurolite and Magnetite about Garnet.—The arrangement of staurolite and garnet is in some instances such as to show that the staurolite is a later development. Its crystals seem sometimes to be developed about and near garnets, as in the rock from the Lion's Head, northwest of Salisbury (number 3431). In the schists of the north end of the ridge called June mountain (northeast of Sheffield village), a crown of staurolite prisms almost encircles an individual of garnet (number 3306 *B*). The garnet is pink, and is filled with microlites (rutile). Between the encircling crown of roughly radial staurolite crystals and the garnet individual is considerable magnetite (see figure 4). The fact that staurolite has not been found except with garnet, though garnet is found unaccompanied by staurolite, taken in connection with the statements just made, shows that staurolite has generally been a later development in the rock, and probably requires more intense metamorphism. In some instances, at least, it is indebted to the garnet for its iron and probably also much of its alumina and silica. In the case of the crown about garnet, we seem to have a true reactionary rim, where the iron of

the garnet has been sufficient to supply the staurolite and leave a residue, which appears as magnetite.

Tourmaline and its secondary Enlargement.—This mineral is specially abundant in the lowest schist bed, occurs usually in black prisms, and in size varies from microscopic dimensions to several centimeters. In the pegmatite veins it is often found in knots as large as one's fist, inclosed in quartz. It is less abundant in both the other horizons, but appears not infrequently in crystals, which are just discernible under the lens. Under the microscope the only noteworthy characters of this tourmaline are the absorption and a marked zonal structure without per-

FIGURE 4.—*Portion of a Crown of Staurolite and Magnetite encircling a garnet Individual.*

In ordinary light. × 33.

ceptible gradations in color. There are nearly always a core and an encircling rim. The core has usually pleochroism in blue to plum tones, whereas the rim shows brown tones like biotite. Sometimes the outline of the core is parallel to the bounding planes (figure 1, *C*). In the graphitic mica schist of the second railroad cut west of Ore Hill (number 3534) undeniable enlargements of tourmaline are found. One of these is represented in figure 1, *B*. The core is oval, and is surrounded by a halo of cloudy opaque material (graphite). It shows the brown tones like biotite. About this rounded and probably detrital core a stoutly colum-

nar crystal of tourmaline has been formed and oriented like the core. The dichroism of the enlargement is unlike the core, as it shows plum tones approaching purple. Secondary enlargements of tourmaline have been observed simultaneously by Whittle in the Green mountains and are described elsewhere* in this volume.

Porphyritic Biotite.—This mineral quite frequently appears in porphyritic blades, generally across the lamination. These are sometimes several millimeters in diameter, and in the rock in which they occur are several times larger than the sericite and biotite of the matrix. Small sericite blades are generally inclosed in this porphyritic biotite.

Ottrelite.—Ottrelite is found in the Mount Washington area, where its minute disks occasionally spangle the surface of the schist. Under the microscope the basal sections appear irregular and somewhat opaque. Prismatic sections are lath-shaped and are sometimes broken across. They show twins both simple and polysynthetic according to the Tschermak law. The index of refraction is higher than that of chlorite, and extinction angles were measured as high as 17 degrees. The absorption is in blue, green and yellow tones. The double refraction is feeble, causing low gray interference colors. It is often difficult to distinguish this mineral from chlorite, which generally accompanies it. Growths of ilmenite similar to those described by Wolff in the New England schists † are not uncommon, but they are here apparently of chlorite, possibly an alteration product of ottrelite. Whittle ‡ has shown that the ottrelite in rocks from the Green mountains is altered extensively to chlorite. The development of ottrelite in the *Salmien superieur* has been made the subject of an extended memoir by Prof. J. Gosselet,|| of Lille. This memoir is important because it throws a great deal of light on the mode of development of other porphyritic constituents of metamorphic schists. M. Gosselet concludes (p. 202) that the ottrelite was formed after the rock was in the condition of a schist or phyllite, since all the constituents of the schist are included in it. Further, the vicinity of the ottrelite crystals shows an impoverishment of quartz. There has also been a local movement of the particles around the ottrelite crystals at the time of their development. The larger grains of hematite and ilmenite have been forced out from the positions occupied by the ottrelite and concentrated in a zone around it. The diversion of the trains of inclusions in the rock as they enter the ottrelite crystal, and the bending of mica scales,

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* Ante, p. 152.

† On some Occurrences of Ottrelite and Ilmenite Schist in New England: Bull. Mus. Comp. Zool., vol. xvi, 1890, pp. 159–165.

‡ An Ottrelite-bearing Phase of a Metamorphic Conglomerate in the Green Mountains: Am. Jour. Sci., 3d ser., vol. xliv, 1892, pp. 274–275.

|| Études sur l'origine de l'Ottrelite, 1re Étude, l'Ottrelite dans le Salmien superieur: Ann. Soc. Geol. Nord, Lille, vol. xv, 1888, pp. 185–318.

show that a general movement occurred in the rock subsequent to the formation of the ottrelite, tending to bring the ottrelite crystals parallel to the schistosity. Professor Gosselet ascribes the development of the ottrelite to heat, of which the cause is unknown.* The spaces left behind the mineral by its movement become filled either at the time or subsequently by muscovite, quartz and oxide of iron, giving rise to peculiar tufts going out from the mineral. Besides the crystals of ottrelite, M. Gosselet describes with great care in the same rocks somewhat irregular rounded areas (*noyaux*) of cloudy, in part doubly refracting, material, surrounded by one or more zones, differing in some respects from the core, which he believes to be the remains of more elementary forms of ottrelite rather than crystals—globulites.

Summary and Conclusions.

From the foregoing, it may be asserted with much probability that the minerals of a porphyritic nature which occur in the schists, viz., feldspar, garnet, staurolite, tourmaline, biotite and ottrelite, were developed in originally clastic rocks as a result of the orographic disturbances to which they have been subjected. Internal mechanical movement seems to have played only a subordinate rôle in their formation, as shearing brings about a crushing and tearing of the constituents not generally observable in the sections. The development of the porphyritic constituents seems therefore to be due to a partial recrystallization of the rock as a result of what I would call *static metamorphism*—*i. e.*, metamorphism in which pressure is the important factor, in contrast to internal movement, though heat and a mineralizer were important adjuncts. The universal distribution of the porphyritic feldspars might indicate that they require a less intense metamorphism for their development than do garnet and staurolite, and this is probably true, though it cannot be asserted that some of these feldspars are not detrital grains like a portion of those described by Wolff.† Evidence has been given to show that the garnet developed largely before the staurolite, and that the latter probably requires for its formation more intense metamorphic action. The staurolite crystals have been developed, at some expense to the garnet, for iron, and probably also alumina and silica. This is shown by the crown of staurolite crystals about garnet in the June mountain schist. This fact, taken in connection with the secondary enlargements of feldspar, garnet, and tourmaline, and the probability of enlargements in the case of staurolite, indicates that the metamorphism which these schists have suffered

* "La formation de l'ottrelite est dû à une production de chaleur dont il faudra chercher la cause." Loc. cit., p. 203.

† Bull. Mus. Comp. Zool., vol. xvi, 1891, p. 175.

was not a continuous process, but occurred in stages, of which there must have been several. It was in one of the later of these stages that the staurolite was developed.

The importance of the enlargement of mineral fragments in clastic rocks as a factor in their alteration by metamorphism, has been emphasized by Irving and Van Hise in their papers on the rocks of the Lake Superior region. This study presents a somewhat different phase of the subject and adds an instance of their occurrence in rocks which have been more profoundly metamorphosed. The investigation here outlined is not completed. The interesting problems of the chemical nature of the reactions involved in the development of the feldspars and their secondary enlargements, and of the other porphyritic constituents, will require for its solution a separation and chemical examination of the different constituents.

In conclusion, I would acknowledge my indebtedness to Dr G. H. Williams and Dr J. E. Wolff for valuable suggestions and criticism.

Explanation of Plate.

Sections of garnetiferous porphyritic Schist from the southeast Slope of Mount Washington, showing secondary Growths of Feldspar.

Locality (number 3104) on road between Joyceville and Plantain Pond.

Figure 1.—A = Secondary growth of feldspar, of which the core has a rounded outline.

B = Feldspar growth with two distinct enlargements indicated by different extinction angles. The core has a micropegmatite structure. Crossed nicols. × 77.

Figure 2.—A = Simply twinned feldspar core with an untwinned enlargement. Crossed nicols. × 48.

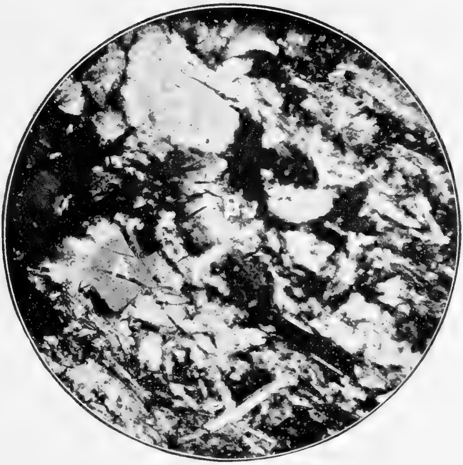

Figure 1

Figure 2.

SECTIONS OF GARNETIFEROUS PORPHYRITIC SCHIST.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 4, PP. 179-190 FEBRUARY 27, 1893

CONTINENTAL PROBLEMS

ANNUAL ADDRESS BY THE PRESIDENT, G. K. GILBERT

(Read before the Society December 30, 1892)

CONTENTS

Introduction.—For a decade attention has been turned to the continents. Through the distribution of animals and plants Wallace has studied the history of the former connection and disconnection of land areas. Theories of interchange of land and water have been propounded by Suess and Blytt. By means of geodetic data Helmert has discussed the broad relations of the geoid to the theoretic spheroid. Darwin has computed the strength of terrestrial material necessary to sustain the continental domes. James Geikie, treating nominally of coast lines, has considered the shifting relations of land and sea, and a half score of able writers have debated the question of continental permanence. The American Society of Naturalists, now holding its annual meeting at Princeton, N. J., devoted yesterday's session to the consideration of such evidences of change in the geography of the American continent as are contained in the distribution of animals and plants. The intercontinental congresses auxiliary to the World's Fair next summer are to be devoted to the discussion of continental and intercontinental themes; and a committee, at the head of which stands one of our vice-presidents, invites the geologists of the world to assemble for the consideration of those broader questions of earth structure and earth history which affect more than one hemi-

sphere. This occasion, too, in which, after three years' sojourn in the land of the raccoon and the opossum, we return to the land of the sable and the beaver, brings forcibly to mind the continental extent of our society and its continental field. It is not strange, then, that the continents have seemed to me a fitting theme of which to speak to you to-day. Realizing not only the breadth and grandeur, but the inherent difficulty of the subject, I do not hope to enlarge the contribution the decade has made, nor shall I attempt to summarize it; neither is it my desire to anticipate the discussions of the World's Fair congress. It is my purpose, rather, to state, as clearly as I may, some of the great unsolved problems which the continents propound to the coming intercontinental congress of geologists.

Differentiation of continental and oceanic Plateaus.—It is one of the paradoxes of the subject that our ideas as to the essential character of the

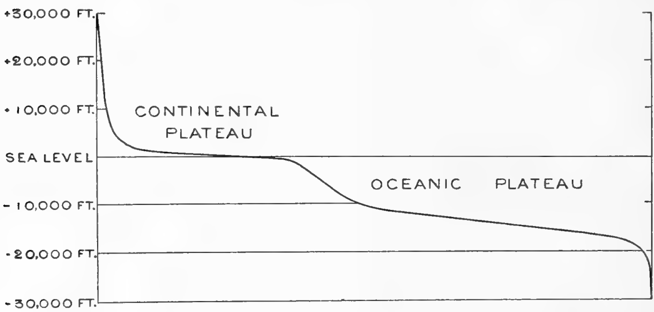

FIGURE 1.—*Generalized Profile, showing relative Areas of the Earth's Surface at different Heights and Depths.*

continents have been greatly modified and clarified by the recent exploration of the sea. The work, especially, of the "Challenger" and the "Blake" in delineating and sampling the bottom of the ocean has given new definitions, not only to the term "deep sea," but also to the term "continent," as they are employed by students of terrestrial mechanics and of physical geography. To the continental lands are now added the continental shoals, and the *depth* of the deep sea is no longer its sole characteristic. Look for a moment at this generalized profile of the earth's surface. It expresses in a concise way the relations of area to altitude, and of both to the level of the sea. Murray, to whose generalizations from the "Challenger" dredgings and soundings the student of continents owes so much, has computed, with the aid of the great body of modern data, the areas of land and ocean bed contained between cer-

tain contours, fourteen in number,* and from his figures I have constructed the profile. Vertical distances represent heights, and horizontal distances represent terrestrial areas. The full width of the diagram from side to side stands for the entire surface of the earth. The striking features of the profile are its two terraces or horizontal elements. Two-fifths of the earth's area lies between 11,000 and 16,000 feet beneath the ocean, constituting a vast submerged plateau, whose mean altitude is — 14,000 feet. This is the plateau of the deep sea. One-fourth of the earth's area falls between the contour 5,000 feet above the ocean and the contour 1,000 feet below, and has a mean altitude of + 1,000 feet. This is the continental plateau. The two plateaus together comprise two-thirds of the earth's surface, the remaining third including the intermediate slopes, the areas of extreme and exceptional depth, and the areas of extreme and exceptional height. Thus in the broadest possible way, and in a manner

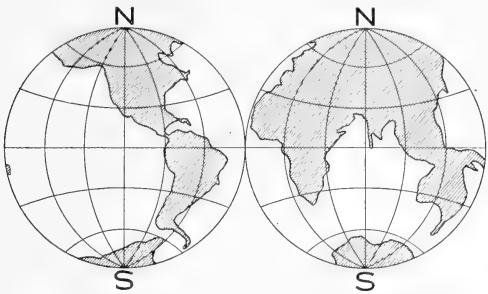

FIGURE 2.—*The continental Plateau as related to the Western and Eastern Hemispheres.*

practically independent of the distribution of land and water, we have the ocean floor clearly differentiated from the continental plateau. It is at once evident that for the discussion of the greater terrestrial problems connected with the configuration of the surface, and especially of the problems of terrestrial mechanics, we must substitute for the continents, as limited by coasts, the continental plateau, as limited by the margins of the continental shoals.

It does not follow from the profile, which, as I have said, represents only the relation of extent to altitude, that all districts of continental plateau are united in a single body, and in point of fact they are not completely united; but the greater bodies are brought together, and the only outlying district is that of the Antarctic continent. Running a line

* John Murray: On the height of the land and the depth of the ocean. Scottish Geographical Mag., vol. iv, 1888, p. 1.

along the edge of the continental shelf where a gentle slope is exchanged for a steep one, and passing freely, as occasion may require, from the coast down to the line of 1,000 fathoms, a continental outline is produced in which North America and Eurasia are united through the shoals of the Arctic ocean, and in which Australia and the greater islands of the East Indies are joined to southwestern Asia. Antarctica alone stands separate, being parted from South America by a broad ocean channel, imperfectly surveyed as yet, but believed to have a depth of between 1,000, and 2,000 fathoms. The lower plateau, or the floor of the deep ocean, is less continuous, being separated by tracts of moderate depth into three great bodies, coinciding approximately with the Pacific, Atlantic and Indian oceans.

Rigidity versus Isostasy.—The first of our continental problems refers to the conditions under which the differentiation of the earth's surface into oceanic and continental plateaus is possible. How are the continents supported? Every part of the oceanic plateau sustains the weight of the superjacent column of water. At the same level beneath the continental plateau each unit of the lithosphere sustains a column of rock both taller and denser than the column of water, and weighing about three times as much. The difference between the two pressures, or the differential pressure, is about 12,000 pounds to the square inch, and this force, applied to the entire area of the continental plateau, urges it downward and urges the oceanic plateau upward. Referring again to the diagram in figure 1, the entire weight of the continental plateau, pressing on the tract beneath it, tends to produce a transfer of material in the direction from left to right, resulting in the lowering of the higher plateau and the raising of the lower. To the question, how this tendency is counteracted, two general answers have been made: first, that the earth, being solid, by its rigidity maintains its form; second, that the materials of which consist the continental plateau and the underlying portions of the lithosphere are, on the whole, lighter than the materials underlying the ocean floor, and that the difference in density is the complement of the difference in volume, so that at some level horizon far below the surface the weights of the superincumbent columns of matter are equal. The first answer regards the horizontal variations of density in the earth's crust as unimportant; the second regards them as important. The first may be called the doctrine of terrestrial rigidity; the second has been called the doctrine of isostasy. At the present time the weight of opinion and, in my judgment, the weight of evidence lie with the doctrine of isostacy. The differential pressure of 12,000 pounds per square inch suffices to crush nearly all rocks, and it may fairly be questioned whether there are any rock masses which in their natural condition near the sur-

face of the earth are able to resist it. The samples of rock to which the pressures of the testing machine are applied have been indurated by drying; but it is a fact familiar to quarrymen that rocks in general are softer as they lie in the quarry below the water-line than after they have been exposed to the air and thoroughly dried. It is probable, therefore, that rocks lying within a few hundred or a few thousand feet of the surface are unable to resist such stresses as are imposed by continents. At greater depths we pass beyond the range of conditions which we can reproduce in our laboratories, and our inferences as to physical conditions are less confident. The tendency of subterranean high temperatures is surely to soften all rocks, and the tendency of subterranean high pressures is probably to harden them. It is not known which tendency dominates; but if the tendencies due to pressure are the more powerful, we are at least assured by the phenomena of volcanism that their supremacy admits of local exception.

Nature of density Differences.—If we accept the doctrine of isostasy and regard the material under the continents as less dense than that under the ocean floors, the question then arises whether the difference in density is due merely to a difference in temperature or whether it arises primarily from differences in composition. This, which may be called the second problem of the continents, is so intimately related to the one which follows that we may pass it by without fuller statement.

What caused the continental Plateau?—The problem of the origin of the continents remains almost untouched. Those who have propounded theories for the formation of mountain ranges have sometimes included continents also, but as a rule without adequate adaptation to the special conditions of the continental problem. So far as I am aware, the subject has been seriously attacked only by our second president, Professor Dana. He postulates a globe with solid nucleus and molten exterior, and postulates, further, local differences of condition, in consequence of which the formation of solid crust on the liquid envelope was for a long period confined to certain districts. In those districts successive crusts were formed, which sunk through the liquid envelope to the solid nucleus, and by their accumulation built up the continental masses. The remaining areas were afterward consolidated, and subsequent cooling shrunk the ocean beds more than it shrunk the continental masses because their initial temperatures (at the beginning of that process) were higher.* That the philosophic mind may find satisfaction in this explanation, it appears necessary to go behind the second postulate and discover what were the conditions which determined congelation in certain districts long before it began in others. Can it be shown that the localization of

* James D. Dana: Manual of Geology, 2d edition, New York, 1874, p. 738.

congelation, having been initiated by an otherwise unimportant inequality, would be perpetuated by any of those cumulative processes which are of such importance in various departments of physics? And can it be shown that such a process of continent-building would segregate in the continental tract certain kinds of matter, and thus institute the conditions essential to isostatic equilibrium? To the first of these questions no answer is apparent, but I incline to the opinion that the second may be answered in the affirmative. If we assume the liquid envelope to consist of various molten rocks arranged in the order of their densities, and if we assume, further, that their order of densities in the liquid condition corresponds to their order of densities in the solid condition, then the successive crusts whose heaping built up the continents would all be formed from the lightest material, and the isostatic condition would be satisfied.

It was the fashion of the last generation of physical geographers to study the forms of continents as delimited by coasts, seeking analogies of continental forms with one another, and also with various geometric figures, especially the triangle. The generalizations resulting from these studies have not yielded valuable ideas, and the modern student is apt to smile at the effort of his predecessor to discover the ideal geometric figure where the unbiased eye sees only irregularity. But barren as were those studies I am not satisfied that their method was faulty; and as a physiographer I have such appreciation of the ideas that sometimes grow from studies of form that I have attempted to apply the old method to the new conception of the continental plateau. Confessing in advance that my only result has been negative, I nevertheless recite what I have done, partly because negative contributions to an obscure subject are not entirely valueless, and partly with the thought that the forms whose meanings I failed to discover may nevertheless prove significant to some other eyes.

What I did was to draw upon a globe the outline of the continental plateau and then view it from every direction. Afterwards I developed the figure upon a plane surface, employing for that purpose a mode of projection which is probably novel. As this mode is not susceptible of mathematical formulation, and therefore will not find place in the literature of cartography, I may be pardoned for applying a trivial name and calling it the *orange-peel* projection. The name almost explains it. Conceive the continental plateau to be outlined upon a spherical orange and the rind of the orange to be divided by a sharp knife along the sinuosities of the outline; conceive then that the portion of the rind thus circumscribed is peeled from the orange and is spread upon a flat surface, the different parts being stretched and compressed so as to pass from

spherical form to plane with the least strain of the rind. The resulting shape is delineated in figure 3. Figure 4 shows the form assumed by the complementary part of the orange peel, which represents, of course, that portion of the ocean outside the continental shoals. In each diagram

FIGURE 3.—*The continental Plateau, developed on a plane Surface.*

the positions of the poles, north and south, are represented by the letters N and S. From the study of these figures, and especially from their study as delineated on the globe, it appeared possible that a portion of the continental plateau might belt the earth as a great circle. The discovery of such a belt would be important, for by assuming that it was

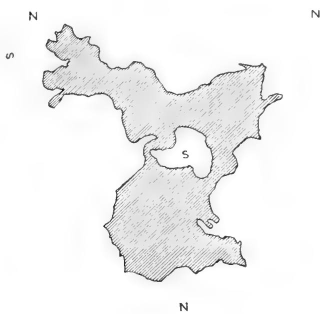

FIGURE 4.—*Oceanic Area complementary to the continental Plateau, developed on a plane Surface.*

originally equatorial we might be led to new hypotheses of continental development. In a rotating liquid sphere the only differentiation of surface condition we can readily conceive is that between equatorial and polar regions, and if such differentiation were sufficient to cause or local-

ize continental elevations, then these elevations would constitute either two polar tracts or else an equatorial belt. Moreover, I have been induced by recent studies of the physical history of the moon to suspect that the earth may at one time have received considerable accessions from without, and that these accessions were made to the equatorial tract. If these suspicions are well founded, peculiar characters may have been given to a tract having the form of a belt. So for a double reason I was led to compare the outline of the continental plateau with a great circle. To this end a great circle was chosen, coinciding as nearly as possible with the line of greatest continental extension, and the projection was so modified as to render the locus of that great circle a straight line. The result appears in figure 5, where the straight line is the projection of the hypothetic ancient equator; and you will probably agree with me that it gives little support to the suggestion that the principal line of continental elevation was originally equatorial.

FIGURE 5.—*Area of continental Plateau, developed with Reference to a great Circle.*

Why do continental Areas rise and fall?—A fourth problem refers to continental oscillations. The geologic history of every district of the land includes alternate submergence under and emergence from the sea. To what extent are these changes due, on one hand, to movements of the sea and, on the other, to movements of the land, and what are their causes? With American geologists the idea, recently advocated, that the chief movements are those of the ocean finds little favor, because some of the most important of the changes of which we are directly cognizant are manifestly differential. Our paleozoic map pictures a sea where now are Appalachian uplands, and uplands where now are low coastal plains and oceanic waters. In Cretaceous time the two margins of what are now the Great Plains had the same height, or at least the western margin was no higher than the eastern; but now the western margin lies from four thousand to six thousand feet above the eastern, and the intervening rock mass appears to have been gently tilted without important internal distortion. Such geographic revolutions are not to be explained by the shifting of the hydrosphere nor by its dilatation and contraction. Neither can they be ascribed to isostatic restoration of an equilibrium deranged

through the transfer of masses by erosion and sedimentation, for that hypothetic process is essentially conservative. Neither is it easy to believe that the two margins of the plains have differed, since the Cretaceous, to the extent of one mile in their radial contraction due to secular cooling of the globe; nor is it easy, at least for the disciple of isostasy, to believe that such a change can have resulted from the localization of deformation consequent on the slowing of the earth's rotation. Each of these processes may have been concerned, but I conceive that the essential factor still awaits suggestion. Our knowledge of surface processes, as compared to subterranean, is so full that the field of plausible epigene hypotheses may be exhausted, but the vista of hypogene possibility still opens broadly.

Are Continents permanent?—The doctrine of the permanence of the continental plateau, enunciated long ago by Dana and more recently advocated, with a powerful array of new data, by Murray and Wallace, has made rapid progress toward general acceptance. Nevertheless its course is not entirely clear, and among the obstacles still to be overcome is one whose magnitude is perhaps magnified for the American student by proximity. All who have studied broadly the stratigraphy of the Appalachian district have concluded that the sediments came chiefly from the east; and the detailed Appalachian work of the past decade is disclosing a complicated history, in which all chapters tell of an eastern paleozoic land, and some chapters seem to testify to its wide extent. At some times the western shore of this land lay east of the site of the Blue Ridge, and there is serious doubt whether the existing belts of coastal plain and submerged continental shelf afford it sufficient space. For the present, at least, the subject of continental permanence must be classed with the continental problems.

Do Continents grow?—According to my own view, there is yet another, a sixth, continental problem deserving the attention of the World's Fair intercontinental congress. We have been told by the masters of our science, and their teaching has been echoed in every text-book and in every class-room, that through the whole period of the geologic record the continents have grown; not that the continental plateaus have been materially extended, not that the pendulum has moved always in one direction, but that the land area has, on the whole, steadily increased. From this doctrine there has been no dissent—and possibly there should be no dissent—but the evidence on which it is founded appears to me so far from conclusive that I venture to doubt.

The evidence employed consists partly in the general distribution of formations as shown by the geologic map and partly in inferences drawn from certain formations which contain internal evidence that they orig-

inated on coasts. With the aid of such data are drawn the outlines of ancient ocean and land at various geologic dates, and from the comparison of these outlines continental growth is inferred. In passing from the formation boundaries of the geologic map to the oceanic limits of the charts of ancient geography, allowance is made for the former extent of non-littoral formations beyond their present boundaries. This allowance is largely conjectural, and the range of possible error is confessedly great. In passing from the observed limits of littoral formations to the coast lines of ancient geography little or no allowance is usually made for the former extent of the formations, and I conceive that great possibility of error is also thus admitted. During a period of oceanic transgression over the land all portions of the transgressed surface are successively coastal, and the coastal deposits they receive are subsequently buried by off-shore deposits. When, therefore, littoral beds are found in remnants of strata surviving the processes of degradation, it is indeed proper to infer the proximity of ancient coasts during their formation, but the inference that they represent the limit of transgression for that epoch may be far from the truth. For these reasons it appears to me that the specific conclusions which have been reached with reference to the original extent of various formations are subject to wide uncertainties; and if this be granted, then but brief attention to a simple law of denudation is necessary to show that the general conclusion may be illusory. The process of degradation by aqueous agencies is chiefly regulated, not by the thickness of formations, but by the height to which they are uplifted. Thus the present extent of most formations is determined in large part by crustal oscillations subsequent to their deposition. As formations are progressively eroded, the underlying and older cannot be attacked until the overlying and younger have been carried away, and so the outcrops of the older of necessity project beyond the boundaries of the younger. The process of vague inference, making indefinite allowance for the unknown quantity of eroded strata, nearly always assigns to the older formation, which projects visibly beyond the newer, a greater original extent. It appears to me thus possible that the greater part of the data from which continental growth is inferred may be factitious and misleading.

Furthermore, inference, such as it is, deals with only one phase of the problem. It is applied to the incursions of the sea upon the land, but it is not applied to the excursions of the land upon the sea. Just as we infer from stratified rocks the presence of the sea, so also we infer from unconformities the sea's absence; and to the student of ancient geography the two classes of evidence are equally important. But the strata, spread widely over the surface of the land, are conspicuous phenomena, while

unconformities are visible only here and there and are usually difficult of determination. For this reason the data from unconformity have never been assembled. Essays toward ancient geography have dealt only with the minima of ancient land, never with its maxima, and the question of continental growth cannot be adequately treated while half of the history is ignored.

We may borrow a figure from the strand of a lake. As the waves roll inward, each records its farthest limit by a line upon the sand, and each obliterates all previous wave lines which it overpasses. The observer who studies the transient record at any point may find a series of lines, of which the highest is the oldest and the lowest is the newest, and he may infer that the lake level was higher when the first wave left its trace, and that the water is receding from the land. But if he continue his observations through many days and fix monuments to record from time to time the lowest land laid bare between the waves, he may discover that the highest wave line and the lowest record of ebb correspond in time with the play of the largest waves, and that the lowest wave line and the highest record of ebb correspond to the play of smaller waves, and thus reach the conclusion that the lake level has remained unchanged. In the study of Time's great continental strand we are not even able to observe directly the wave lines of rhythmic transgression, but infer their positions from data often ambiguous, and of the lower wave limits, the lines of maximum regression, we are absolutely ignorant.

It may be true that *a priori* considerations afford a presumption in favor of continental growth, but such presumption should not be permitted to give color to evidence otherwise neutral; and, moreover, it is not impossible to discover an *a priori* presumption in favor of continental diminution. Assuming that hypogene agencies cause continental areas to rise above the ocean, the work of epigene agencies constantly tends to remove the projecting eminences and deposit their material about their margins, so as to extend the area of the continental plateau. Thus we have a strong *a priori* presumption in favor of continental growth. On the other hand, if we admit the principle of isostatic equilibrium, then the continental eminences have low density; and as they are worn away by epigene processes the material which rises from below to restore them has greater density and maintains a somewhat less altitude. The process of isostatic restoration tends thus toward the permanent leveling of continents, and if the hypogene initiative should cease the continents would ultimately be reduced to ocean level, and finally, through processes of solution, to a level below the ocean; so, assuming the initiative processes of the under earth to be of finite duration, the work of terrestrial degradation, combined with isostatic restoration, should afford a

continental history characterized in an earlier stage by growth and in a later stage by decadence. In our ignorance of subterranean forces we should use such *a priori* considerations only as a means for the suggestion of hypotheses. As they have doubtless served to promote the theory of continental growth, they should also be permitted to indicate the possibility of continental retrogradation.

Summary.—The problems of the continents have been touched to-day so briefly that a summary is almost superfluous. The doctrine of isostasy, though holding a leading position, has not fully supplanted the doctrine of rigidity. If it be accepted, there remains the question whether heat or composition determines the gravity of the ocean beds and the levity of continents. For the origin of continents we have a single hypothesis, which deserves to be more fully compared with the body of modern data. The newly determined configuration of the continental mass has yielded no suggestion as to its origin. The cause of differential elevation and subsidence within the continental plateau is unknown and has probably not been suggested. The permanence of the continental plateau, though highly probable, is not yet fully established; and the doctrine of continental growth, though generally accepted, has not been placed beyond the field of profitable discussion. Thus the subject of continents affords no less than a half dozen of great problems, whose complete solution belongs to the future. It is not altogether pleasant to deal with a subject in regard to which the domain of our ignorance is so broad; but if we are optimists we may be comforted by the reflection that the geologists of this generation, at least, will have no occasion, like Alexander, to lament a dearth of worlds to conquer.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 4, PP. 191-204 MARCH 24, 1893

COMPARISON OF PLEISTOCENE AND PRESENT ICE-SHEETS

BY WARREN UPHAM

(Read before the Society December 29, 1892)

CONTENTS

EXISTING ICE-SHEETS AND GLACIERS.

The guiding principle of geologic investigation, brought out most clearly by Lyell, requires us to seek the explanation of past changes of the earth by observation and study of agencies which are now in operation, producing similar changes during the present epoch. From such studies of the Swiss glaciers, Agassiz, Forbes, Tyndall and others have given to us the theory of the formation of the drift by land ice, so that the comparatively small district of the Alps supplied the clue for deciphering the records of the latest completed chapter of the geologic history of northwestern Europe and the northern half of North America. Glaciers of other regions in the eastern hemisphere, notably of the Himalayas and

of Norway, have also contributed much to our knowledge of the ice-sheets of the Pleistocene or glacial period. The vast ice-sheets of that time, however, are adequately exemplified at the present day only by the Antarctic and Greenland ice-sheets, less completely and on a much smaller scale by the yet very instructive Malaspina glacier, and in some respects they may be profitably compared with the Muir glacier, which is the most fully studied ice-field of America or perhaps of the world.

The Antarctic Ice-sheet.—Land ice surrounds the south pole to a distance of 12 to 25 degrees from it, covering, according to Sir Wyville Thomson, about 4,500,000 square miles. Its area is thus slightly greater than that of the Pleistocene ice-sheet of North America, which covered about 4,000,000 square miles, while the confluent Scandinavian and British ice-sheets appear to have enveloped no more than 2,000,000 square miles, including the White, Baltic, North and Irish seas, whose areas were then occupied by the continental *mer de glace.* Whether the Antarctic ice-sheet covered an equal or greater extent in the Pleistocene period, contemporaneous with the glaciation of now temperate regions, we have no means of knowing. Along a portion of its border of perpendicular ice-cliffs Sir J. C. Ross sailed 450 miles, finding only one point low enough to allow the upper surface of the ice to be viewed from the masthead. There it was a smooth plain of snowy whiteness, extending as far as the eye could see. That this ice-plain has a considerable slope from its central portions toward its boundary is shown by its abundant outflow into the sea, by which its advancing edge is uplifted and broken into multitudes of bergs, many of them tabular, having broad, nearly flat, tops. As described by Moseley in "Notes by a Naturalist on the *Challenger*," these bergs give strange beauty, sublimity and peril to the Antarctic ocean, upon which they float away northward until they are melted. Many parts of the borders of the land underlying this ice-sheet are low and almost level, as is known by the flat-topped and horizontally stratified bergs, but some other areas are high and mountainous. Due south of New Zealand the volcanoes Terror and Erebus, between 800 and 900 miles from the pole, rising respectively about 11,000 and 12,000 feet above the sea, suggest that portions or the whole of this circumpolar continent may have been recently raised from the ocean to form a land surface, which on account of its geographic position has become ice-clad.

The Greenland Ice-sheet.—Inside its border of mountains Greenland is enveloped by an ice-sheet which has a length of about 1,500 miles, from latitude 60° 40′ to latitude 82°, with a probable average width of 400 miles or more, giving it an area of 600,000 square miles. On the east this ice-sheet in some places stretches across the mountains, and the coast consists of its ice-cliffs; and on the west glaciers flow from the inland ice

through gaps of the mountains to the heads of the many fjords and bays, where the outflowing ice is broken into bergs of every irregular shape and borne away by the sea. One of these ice-streams, discovered and named by Kane the Humboldt glacier, is 60 miles wide where it enters Peabody bay, above which it rises in cliffs 300 feet high.

The altitude and slopes of the Greenland ice-sheet have been determined by Nordenskiöld, Peary, and Nansen. Nordenskiöld's journey in July, 1870, to the east from the head of Aulatsivik fjord, near latitude 68° 20′, is estimated to have extended about 35 miles upon the ice-sheet, and the altitude reached was 2,200 feet. From nearly the same starting point, Nordenskiöld, in July, 1883, went onto the ice-sheet about 73 miles, to a height of about 4,950 feet; and two Lapps, traveling with the peculiar snowshoes called "ski," advanced a probable distance of 45 or 50 miles farther, where the barometers indicated a height of 6,386 feet. Land in the interior, free of ice and bearing vegetation, which Nordenskiöld hoped to reach, was not found; and no nunatak, or projecting top of hill or mountain, above the ice surface has been yet discovered more than 40 or 50 miles inside the ice-covered area.

Lieutenant R. E. Peary, of the United States Navy, in June and July, 1886, accompanied by Christian Maigaard, made the next important exploration of the inland ice, going eastward from the head of Pakitsok fjord, on the northeastern part of Disco bay, in latitude 69° 30′. They advanced to a distance of about 100 miles from the edge of the ice, attaining an altitude of about 7,500 feet. In concluding the narrative of this journey,* after describing the needful outfit, Peary remarked: "To a small party thus equipped, and possessed of the right mettle, the deep, dry, unchanging snow of the interior . . . is an imperial highway, over which a direct course can be taken to the east coast." It was also suggested that the unexplored northern shore lines of Greenland may be most readily mapped by expeditions across the high inland ice. This sagacious suggestion Peary has since in part fulfilled by his very successful expedition from May 15 to August 6 of this year, in which he crossed the northwestern and northern parts of this ice-sheet, reaching altitudes of 5,000 to 8,000 feet, and determining approximately the northern boundary of the ice from Petermann fjord to the eastern coast at Independence bay, in latitude 81° 37′ and longitude 34° west from Greenwich.

In August and September, 1888, Dr Fridtjof Nansen, with five companions, crossed the ice-sheet of Greenland from east to west between latitude 64° 10′ and 64° 45′. The width of the ice there is about 275 miles, extending into the ocean on the east, but terminating on the west

*"A Reconnoissance of the Greenland Inland Ice," Bull. Am. Geog. Soc., vol. xix, pp. 261-289, September 30, 1887.

about 14 miles from the head of Ameralik fjord and 70 miles from the outer coast line. For the first 15 miles in the ascent from the east, rising to the altitude of 1,000 meters, or 3,280 feet, the average gradient was nearly 220 feet per mile. In the next 35 miles an altitude of 2,000 meters, or 6,560 feet, was reached; and the average gradient in this distance, between 15 and 50 miles from the margin of the ice, was thus about 94 feet per mile, or a slope very slightly exceeding one degree. The highest part of the ice-sheet, about 112 miles from the point of starting, was found to have an altitude of 2,718 meters, or about 8,920 feet. Its ascending slope, therefore, in the distance from 50 to 112 miles was about 38 feet per mile. Thence descending westward, the gradients are less steep, averaging about 25 feet per mile for nearly 100 miles to the altitude of 2,000 meters, about 63 feet per mile for the next 52 miles of distance and 1,000 meters of descent, and about 125 feet per mile for the lower western border of the ice.*

But Greenland has not always been thus ice-enveloped. During the middle or earlier portions of the Tertiary era forest trees belonging to a temperate flora extended northward in western Greenland to the Arctic circle. Going much farther back to inquire the origin of this great island, we find that it is an outlier of the North American plateau of Archæan rocks, which comprises also Ellesmere land, the eastern part of North Devon, Baffin land, Labrador and the country around Hudson bay, stretching thence southwestward to lakes Huron, Superior and Winnipeg, and westward to Athabasca, Great Slave and Great Bear lakes, and to Coronation gulf of the Arctic sea. The greater part of the Arctic archipelago, however, consists of Paleozoic strata. During long Mesozoic and Tertiary ages of higher altitude of these regions subaërial stream erosion formed the channels which divide the Arctic islands, the basin and valley of Hudson bay and strait and those of Baffin bay and Davis strait, which now by subsidence separate Greenland from the mainland. More ample oceanic circulation, carrying warmth from tropical and temperate latitudes to the Arctic sea, was probably the cause of the formerly luxuriant vegetation of Greenland; but during the ensuing Pleistocene period its ice-sheet was for some time even more extended and deeper than now, as is shown by the glaciation of the rock surface high up on the sides of the fjords.

The Malaspina Glacier or Ice-sheet.—The comparatively small Malaspina ice-sheet, stretching from the Saint Elias range to the shore of the Pacific ocean, has been described as follows by its principal explorer, Professor I. C. Russell, after his two expeditions of 1890 and 1891: †

* The First Crossing of Greenland, 2 vols., 1890.

† "Mount Saint Elias and its Glaciers," Am. Jour. Sci., III, vol. xliii, pp. 169-182, with map, March, 1892. The report of the first expedition, in 1890, is given by Russell in the National Geographic Magazine, vol. iii, pp. 53-203, with 19 plates, and 8 figures in the text, May 29, 1891.

This glacier extends with unbroken continuity from Yakutat bay seventy miles westward, and has an average breadth of between twenty and twenty-five miles; its area is approximately 1,500 square miles, . . . a vast, nearly horizontal plateau of ice, with a general elevation of about 1,500 feet. The central portion is free from moraines and dirt, but is rough and broken by thousands and tens of thousands of small crevasses. Its surface is broadly undulating, and recalls the appearance of portions of the rolling prairie lands west of the Mississippi. . . . On looking down on the glacier from an elevation of two or three thousand feet on the hills bordering it on the north, even on the wonderfully clear days that follow storms, its limits are beyond the reach of vision. From any commanding station overlooking the Malaspina glacier, as from the summit of the Chaix hills, for example, one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed of bowlders and stones. Outside of this, and forming a belt concentric with it, is a forest-covered area, in many places four or five miles wide. . . .

The moraines not only cover all of the outer border of the glacier, but stream off from the mountain spurs that project into its northern border. . . . The stones and dirt previously contained in the glacier are . . . concentrated at the surface, owing to the melting of the ice that contains them. This is the history of all of the moraines of the Malaspina glacier. They are formed of the débris brought out of the mountains by the tributary Alpine glaciers, and concentrated at the surface by reason of the ablation of the ice. . . .

The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce trees, some of which are three feet in diameter, and cottonwood, alder and a great variety of shrubs and bushes, together with rank ferns, which grow so densely that one can scarcely force a passage through them. The vegetation grows on the moraines resting on the ice, which in many places is not less than a thousand feet thick. . . . It is only on the stagnant border of the ice-sheet that forests occur. The forest-covered area is, by estimate, between twenty and twenty-five square miles in extent.

The drainage of the Malaspina glacier is almost entirely interglacial or subglacial. There is no surface drainage, excepting in a few localities where there is a surface slope, but even in such places the streams are short and soon plunge into a crevasse or a moulin and join the drainage beneath.

On the lower portions of the Alpine glaciers, tributary to the Malaspina, there are sometimes small streams coursing along in ice channels, but they are short-lived. On the borders of these tributaries there are frequently important streams, flowing between the ice and a mountain slope, but where these come down to the Malaspina they flow into tunnels and are lost to view.

Along the southern margin of the Malaspina glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier, or rise like great fountains from the gravel and bowlders at its base. All of these streams are brown and heavy with sediment and overloaded with bowlders and stones.

One of the largest streams draining the glacier is the Yahtse. This rises in two principal branches at the base of the Chaix hills, and, flowing through a tunnel some six or eight miles long, emerges at the southern border of the glacier as a

swift, brown flood, fully one hundred feet across and fifteen or twenty feet deep. The stream, after its subglacial course, spreads out into many branches, and has built up an alluvial fan which has invaded and buried thousands of acres of forest. In traversing the coast from the Yahtse to Yakutat bay, we crossed scores of ice-water streams which drain the ice-field to the north. The greater part of these could be waded, but some of them are rivers which it was impossible to ford.

Orogenic disturbances formed the Saint Elias range since the beginning of the Pleistocene period, for its basal portion consists of the late Pliocene and Pleistocene Pinnacle and Yakutat formations, above which the Saint Elias schist has been overthrust. Fossil marine shells, all of which are represented by species now living in the adjacent ocean, were collected by Russell in the cliffs above Pinnacle pass at the height of 5,000 feet above the sea. The following summary of the history of this range is given by Russell: *

Not only was a part, at least, of the Pinnacle system deposited during the life of living species of mollusks, but also the whole of the Yakutat series, the stratigraphic position of which is, if my determination is correct, above the Pinnacle system. After the sediments composing the rocks of these two series were deposited in the sea as strata of sand, mud, etc., they were consolidated, overthrust, faulted and upheaved into one of the grandest mountain ridges on the continent. Then, after the mountains had reached a considerable height, if not their full growth, the snows of winter fell upon them, and glaciers were born. The glaciers increased to a maximum, and their surfaces reached from a thousand to two thousand feet higher than now on the more southern mountain spurs, and afterward slowly wasted away to their present dimensions. All of this interesting and varied history has been enacted during the life of existing species of plants and animals.

The Muir Glacier.—According to the descriptions and maps of Professors G. Frederick Wright † and H. F. Reid ‡ and Mr H. P. Cushing, ‖ the Muir glacier, which is situated some 200 miles southeast of Mount Saint Elias, has an area of about 350 square miles, and the area inclosed by its watershed is about 800 square miles. It receives many tributary glaciers, whose areas are included in this estimate. The slope of the main glacier for 10 miles or more next to its termination in the sea at the head of Glacier bay is about 100 feet per mile. Its frontal cliffs, which shed multitudes of bergs into the sea, had in 1890 an extent of 1¾ miles, and rose in a vertical wall of ice 130 to 210 feet above the water, which, within 300 feet from the ice-front, has a maximum depth of 720 feet. Between the observations of Professor Wright in 1886 and those of

* Nat. Geog. Mag., vol. iii, pp. 172, 173.

† Am. Jour. Sci., III, vol. xxxiii, pp. 1–18, with map, January, 1887: The Ice Age in North America, 1889, chapter iii.

‡ Nat. Geog. Mag., vol. iv, pp. 19–84, with 16 plates and 5 figures in the text, March 21, 1892.

‖ Am. Geol., vol. viii, pp. 207–230, with map, October, 1891.

Reid and Cushing in 1890, the ice-front had receded one-third to two-thirds of a mile.

In 1886 the height of the ice-cliffs above the water was found by Wright to be 250 to 300 feet, and the rates of forward motion of the most prominent ice pinnacles near to the front and within a half mile back from it were roughly measured by him and found to vary from 160 feet to 9 feet per day, the maximum being that of a pinnacle close to the projecting middle of the terminal cliffs. In 1890, however, Reid and Cushing measured the rates of the glacial currents in a more accurate way by observations of flags set on the surface of the glacier one-fourth to one-half of a mile back from its then nearly straight and much lower front, and found the maximum movement near the center to be only about seven feet per day. In respect to the apparent discrepancy of these determinations in 1886 and 1890, it is to be remarked that the ice pinnacles, belonging to the most fractured and crevassed portions of the glacier, probably move onward faster than its more even tracts, which can be traversed and marked by flags, and that the two different years between which the front was withdrawn so far may have been considerably unlike in the meteorologic conditions governing the flow of the glacier. The abundant observations of Helland, Steenstrup and others on the rates of outflow of glaciers into the fjords and bays of the western coast of Greenland show that there the glacial advance ranges frequently from 30 to 65 feet daily, and in at least one case is about 100 feet.* Narrow glaciers in Alpine valleys move only a few feet daily; but the broad glaciers of polar regions, when they terminate in the sea, often move at their ends much more rapidly, as 30 to 50 feet or more per day.

The Muir glacier, like the Malaspina ice-sheet and other glaciers of the Saint Elias region, is fast retreating. From the narrative of Vancouver's exploration of this coast in 1794, and from observations by Wright, Reid, and Cushing, of freshly glaciated rock surfaces far outside and also far above the present glacier, it appears sure that only one to two centuries ago the Muir glacier stretched some twenty miles farther than now, nearly to the mouth of Glacier bay. Its advance to this maximum area had perhaps occupied a considerably longer time than its retreat, but the whole time of both advance and recession appear to be geologically recent. In its forward movement forests became enveloped in the gravel and sand discharged by streams from the glacier, and they were then overridden by the ice advance, so that now on its retreat the still standing trees are being uncovered by the channeling of streams.

During the summer of 1890 the rate of ablation of the frontal part of

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* H. Rink: "The Inland Ice of Greenland," Scottish Geog. Mag., vol. v, 1889, pp. 18–28. Nature, December 29, 1887.

the Muir glacier was about 14 inches per week, which would lower its surface probably 15 or 20 feet in the whole season. This corresponds approximately with the ablation of the Mer de Glace in Switzerland, ascertained by Forbes to be 24½ feet between June and September in 1842, while in some exceptional cases the ablation of glaciers in summer has been found to be as much as one foot a day.

One other point of great significance brought out by these investigations of the Muir glacier is the approximate determination of the rate of glacial erosion upon its rock bed. Measurements of the sediment in the water of the copious subglacial streams, and estimates of the quantity of water annually discharged from the rainfall and snowfall of the Muir basin, indicate, according to Wright's computations, an average erosion of one-third of an inch for all the ice-clad area in a year, while according to Reid it would be about three-fourths of an inch.

Inferences from Comparisons of present and Pleistocene Ice-sheets.

Probable surface Slopes and Thickness of the Pleistocene Ice-sheets of North America and Europe.—In North America the upper limits of the Pleistocene glaciation on mount Katahdin, the Catskills, the Three buttes or Sweet Grass hills of Montana, the Rocky mountains north of the international boundary, and the mountains of British Columbia, give us reliable information of the thickness of the ice-sheet in the vicinity of these high elevations of land. Its depth is computed by Dana to have been about two miles on the Laurentide highlands, between the Saint Lawrence and Hudson bay, whence the ice flowed radially outward in all directions, during its maximum stage overtopping the White, Green and Adirondack mountains. In British Columbia, according to Dr G. M. Dawson, its maximum depth was about 7,000 feet. These thicknesses, however, which seem well determined, would not give to the borders of the North American ice-sheet surface slopes of more than about 25 to 30 feet per mile, whereas the Greenland ice-sheet is known to have surface gradients of 100 to 200 feet per mile. Apparently slopes of at least 50 feet or more per mile for the outer portion of the ice-sheet are required to produce strong glacial currents, such as transported bowlders 1,000 miles, from the eastern side of the southern part of Hudson bay where it narrows into James bay southwestward to southern Minnesota, and such as carried Scandinavian bowlders likewise about 1,000 miles, from their sources to central Russia. The Pleistocene ice-sheets could have had gradients comparable in steepness with those of the Greenland ice-sheet only by epeirogenic uplifts of the central portions of their areas to heights

at least several thousand feet above their present altitudes. These epeirogenic movements of uplift, suggested by the ice-sheet of Greenland, I believe to have been the cause of the climatic changes by which the ice-sheets of North America and Europe were accumulated.

The depth of the fjords and now submarine valleys on the coasts of the northern half of our continent indicate that the borders of our glaciated area were mostly uplifted 2,000 to 3,000 feet, and the preglacial elevation of the central parts of Canada was probably 5,000 feet or more, giving the necessary slope for the outflow of the ice-sheet, excepting so far as that outflow was due to the thickness of the ice. The same arguments for high preglacial altitude of Scandinavia have been recently well stated by Mr T. F. Jamieson, who notes the depth of the Christiania fjord as 1,380 feet, of the Hardanger fjord, 2,624 feet, and of Sogne fjord, the longest in Norway, 4,080 feet.*

Probable Rates of Erosion by Pleistocene Ice-sheets.—The Muir glacier is found to be eroding its rock bed at the rate of about three-fourths of an inch yearly, or one foot in sixteen years, and six feet in a century. Doubtless the erosion by the ice-sheets of the glacial period was equally rapid in the zone of most efficient action, which may have been usually from 50 to 200 miles inside the ice boundary. In 1,000 years this zone would be eroded to an average depth of 40 feet, and in 5,000 years 200 feet. Farther within the ice-covered area the erosion was probably somewhat less, but during the recession of the ice-sheet, and perhaps also during its accumulation, the maximum rate of erosion would prevail successively upon all parts of the drift-bearing regions. In the light of this comparison with the modern Muir glacier, it is evident, from the volume of the drift and the topographic features of the country, that a geologically brief period, at the longest perhaps 10,000 or 20,000 years, would suffice for the observed volume of the Pleistocene glacial erosion and resulting drift.

Subglacial and englacial Transportation of Drift.—Under this heading an ample discussion would require much space. It may be therefore sufficient to state that the observations of the inland ice of Greenland by Holst and of the Malaspina glacier by Russell, reäffirming the conclusions reached through investigations of the North American drift by Dana, Shaler, C. H. Hitchcock, N. H. Winchell and others, including myself, seem to me to prove undeniably that the Pleistocene ice-sheets contained much drift in their lower portions to heights of probably 1,000 to 1,500 feet above the ground. This transportation of drift within the ice seems to me to have been equally important, and almost equal in amount, with the subglacial transportation. Professor James Geikie,

*Geol. Mag., III, vol. viii, pp. 387–392, September, 1891.

however, in Great Britain, and Chamberlin and Salisbury, with McGee and others, in this country, think that there was only very scanty englacial drift. My reasons for believing that it was of large amount I have stated in several recent papers, three of which have been presented before this Society.*

Rapidity of final Ablation of the Ice-sheets.—The rates of observed ablation of the Muir glacier and the Mer de Glace suggest that during the closing stage of the glacial period the ice-sheets may have been melted away very fast. If such ablation prevailed every summer for one or two centuries, it must melt 2,000 to 4,000 feet of ice, which was approximately the thickness of the Pleistocene ice-sheet from central New England westward across the Laurentian lakes to Minnesota and southern Manitoba. This accords with the apparent duration of the glacial lake Agassiz for only about 1,000 years, and with the evidently very rapid accumulation of the eskers, of their associated sand plains and plateaus, of the valley drift, and also, as I confidently think, of the drumlins. There were indeed many times of halt or reädvance of the ice-front, interrupting its general retreat, as shown by the terminal moraines, of which Professor Chamberlin, Mr Frank Leverett and others have mapped no less than fifteen or twenty in their order from south to north in Ohio, Indiana, Illinois, and southern Michigan; but such halts forming large moraines on each side of Lake Agassiz were demonstrably of short continuance, only for a few decades of years, and the whole departure of the ice-sheet from the southern end of this glacial lake to Hudson bay was geologically very rapid.

The causes for the sudden departure of the ice were therefore probably as exceptional and unique in their character as for its accumulation, and I think that they were indeed exactly the reverse of those before assigned for the inauguration of the glaciation. Beneath the load of ice thousands of feet thick the land sank, and when the ice-sheets were at their maximum area and during their retreat the glaciated lands stood mostly somewhat lower than now. The depression from the preglacial altitude was virtually equivalent to a transfer of the Greenland ice-sheet to the present temperate latitudes and comparatively low lands of the provinces of Quebec and Ontario and the northern United States, where that vast sheet of ice would be rapidly melted during all the summer months and more slowly in spring and autumn, until within probably a few hundred years it would entirely disappear.

*"Inequality of Distribution of the Englacial Drift," Bull. Geol. Soc. Am., vol. iii, 1891, pp. 134–148. "Criteria of Englacial and Subglacial Drift," Am. Geol., vol. viii, pp. 376–385, December, 1891. "Conditions of Accumulation of Drumlins" (presented in preliminary outlines at the Rochester meeting of the Geological Society, August, 1892), Am. Geol., vol. x, pp. 339–362, December, 1892. "Eskers near Rochester, N. Y." read before the Society at this Ottawa meeting.

Modes of Deposition of the englacial Drift.—Again, on this topic, which, like the ways of transportation of the drift, would need too much space, for its adequate presentation here, I may refer to my several papers before cited. It is desirable, however, to call special attention to the discrimination by Holst of the enclosed drift and the subglacial drift of the Greenland ice-sheet.* In New England and in Minnesota, the Dakotas, and Manitoba, I find corresponding divisions of the sheet of till, the lower part being shown by its hard and compact condition and by other characters to be the ground moraine of the ice-sheet, while the upper part, which is comparatively loose, with more plentiful large bowlders, appears to have been dropped from an englacial or superglacial position when the ice melted.

Russell, in the later paper already quoted from, discusses in a very instructive manner, by analogy with the products of the Malaspina glacier, the origin of Pleistocene eskers and kames, glacial flood-plains of gravel and sand, and somewhat similar high lacustrine plains and terraces. All the explanations which he thus gives are undoubtedly applicable generally or at least in some localities to the drift formations of the Glacial period ; but, as noted in my foregoing paper on the Pinnacle hills and Pittsford eskers, near Rochester, New York, I think that mainly the retreat of the Pleistocene ice-sheet was so rapid that its drainage then was almost wholly by superglacial streams, in whose open channels the eskers of the northern United States and Manitoba, so far as I have studied them, appear to have been formed.

The accumulation of drumlins, which has been so difficult of explanation, seems to me referable to convergent currents of the ice-sheet during its retreat amassing its englacial drift in these peculiarly moulded hills, this drift having been first exposed on the ice surface by ablation, like that on the outer part of the Malaspina glacier, then enveloped again in the ice as a drift stratum, and finally carried into these accumulations beneath the ice.†

Origin of Forest Beds between Deposits of Till.—On extensive tracts of the Mississippi basin, most notably in Indiana, Illinois, Iowa and southeastern Minnesota, the drift sheet comprises in many places, and sometimes wellnigh in every well of whole townships, a horizon marked by prostrate trunks of trees, fallen leaves or rushes and grass of swamps, or occasionally by layers of peat, above and beneath which the sections pass through till. In different districts the forest beds differ in their relationship to the terminal moraines, so that they appear to represent more than one stage of ice advance after at least a considerable retreat. Per-

*Am. Naturalist, vol. xxii, pp. 589-598 and 705-713, July and August, 1888. Am. Geologist, vol. viii, pp. 383, 384, December, 1891.

†Am. Geologist, vol. x, pp. 339-362, December, 1892.

haps the most extensive and continuously preserved forest bed is that described by McGee in northeastern Iowa, where he believes that it bears testimony of a very long interglacial epoch, much exceeding the time since the end of the Glacial period.* But the drift-covered and forest-clad borders of the Malaspina glacier show that this and other vegetal deposits between beds of till might be formed by oscillations of the ice-front, sometimes probably reädvancing 100 or 200 miles, but in other cases perhaps only a few miles, as may often have accompanied the formation of terminal moraines.

The Ice Age viewed as a continuous and geologically brief Period.

General Consideration of the Question.—This comparison of the ice-sheets of present and past times seems to me best accordant with a reference of all our glacial drift to a single continuous epoch of glaciation, which, though occupying probably 10,000 years or perhaps twice or thrice that time, was yet brief in comparison with the duration of most other recognized geologic epochs. The outflow of the upper part of the Pleistocene ice-sheets probably exceeded the currents of narrow alpine glaciers, but was less than the advance of broad and deep polar glaciers which end in the sea. For the journey of Pleistocene bowlders 1,000 miles in the ice-sheet, somewhat less than 3,000 years would be required if the average of the glacial currents was five feet per day. The amount of the glacial erosion and of the drift, when compared with the erosion by the Muir glacier, imply a short rather than a long duration of the Ice age. This conclusion is further affirmed by the continuance of the same species of the marine molluscan faunas from the beginning of the Glacial period to its end and to the present day.

In the light of these considerations, therefore, we are led to question whether the generally accepted doctrine of duality or plurality of Pleistocene epochs of glaciation, with long interglacial epochs, rests on a secure basis. Under the stimulus of Dr James Croll's brilliant theory referring the Ice age to astronomic causes, many European and American glacialists have interpreted forest beds and other fossiliferous beds intercalated between deposits of till as good evidence of long, mild epochs dividing successive times of glaciation; but the partially forest-covered Malaspina ice-sheet indicates, as I believe, that these beds record only temporary oscillations of the ice boundary, not necessarily nor probably occupying any long time. Through reliance on such evidence in Minnesota and

* "The Pleistocene History of Northeastern Iowa," in the Eleventh Annual Report of the U. S. Geol. Survey for 1889–90.

adjacent areas, I was led thirteen years ago to the belief that the Ice age comprised two or more glacial epochs; but within the past year I have been gradually returning to the opinion which I previously held while engaged with Professor C. H. Hitchcock on the New Hampshire geological survey, that the Pleistocene glaciation was essentially a unit.*

Other evidences which have been regarded by Chamberlin, Salisbury, and McGee, as indicative of a long interglacial epoch, drawn from the Pleistocene erosion of the Mississippi river, the Ohio and its tributaries, the Susquehanna and other rivers of the Atlantic slope, appear to me to admit a different interpretation. As I see the late Pliocene and Pleistocene history of this region, a great uplift of the continental plateau closed the Tertiary era and ushered in the Quaternary. During a long time the land stood at a high altitude, and in the earlier part of this time the Lafayette gravel and sand beds were deposited by the rivers eroding the mountain and highland portions of their basins and spreading these beds in their larger valleys and on the coastal plain; but before the elevation attained its maximum, causing the Pleistocene ice accumulation, the streams, no longer overloaded in proportion to their steeper descent, had eroded large portions of the Lafayette formation. By the ice weight the earth's crust at last was depressed, so that when the ice-sheet in the Mississippi valley reached its farthest limit it was bordered by a shallow lake, into which the fine silt of the glacial streams was carried and deposited as loess, upon which higher portions of the loess were afterward brought by river floods. According to this view, the glacial period there appears to me to have been continuous, with retreats and reädvances of the ice-front, but without division by long interglacial epochs. This opinion, however, is put forth in no criticising or dogmatic spirit, but with a sense of my obligation to present the results of my studies, in which I am surely as liable to err as others, for the discovery of the Pleistocene history of our continent.

Probable Synchronism of Glaciation in North America and Europe.—The glacial drift of Europe also seems to me, after reading and pondering Professor James Geikie's recent very able paper arguing for five glacial epochs there,† to be more probably referable to one epoch of continuous but fluctuating glaciation, which appears, by a comparison of the Postglacial oscillations of the Scandinavian peninsula and of our northeastern Atlantic coast, to have been at least approximately synchronous with the Glacial period in America.‡ On both continents it has been com-

* For arguments sustaining this view, see Professor G. F. Wright's paper, "Unity of the Glacial Epoch," Am. Jour. Sci., III, vol. xliv, pp. 351–373, November, 1892.

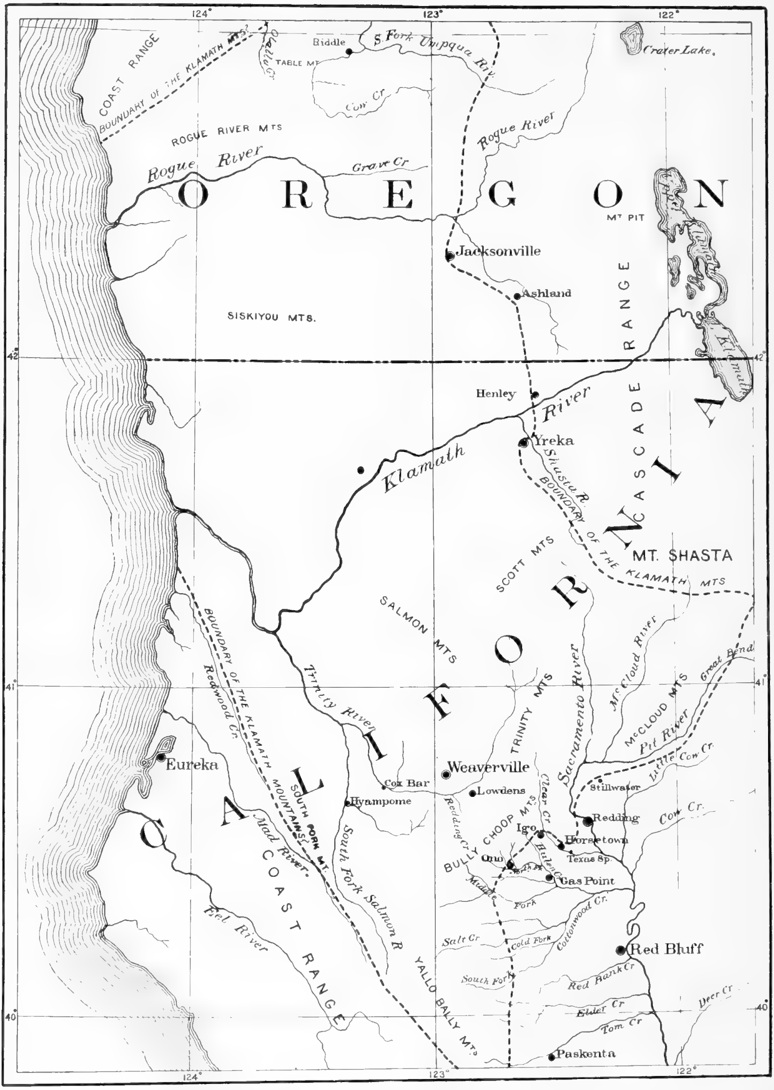
† "On the Glacial Succession in Europe," Trans. Roy. Soc. Edinb., vol. xxxvii, pp. 127–149, with map, May, 1892.

‡ Bull. Geol. Soc. Am., vol. iii, 1892, pp. 508–511.

puted, from various means of measurement and estimate, that the ice-sheets were finally melted away some 6,000 to 10,000 years ago.

Relation of the Ice Age to human and geologic History.—In Europe Professor Geikie has shown that men had reached the neolithic stage of their development before the ice-sheet of Denmark and Scandinavia vanished; and similarly in California neolithic implements, probably contemporaneous with the Ice age, are found in gravels under the lava of Table mountain. Other discoveries of stone implements have been made by Dr Abbott and Professors Putnam and Shaler in the late glacial gravels of Trenton, New Jersey; by Mr J. B. Tyrrell, of the Canadian Geological Survey, in a beach of the glacial lake Agassiz; and by Mr McGee in the sediment of the last great flood of the Pleistocene lake Lahoutan.

The accumulation of the Pleistocene ice-sheets took place at or near the beginning of man's existence, but was close to the present page in the very long record of geology. The preglacial uplifting of the land apparently occupied a far longer time than its glaciation, but both may be well referred, as by Hilgard and Spencer, to the Quaternary era, which also, according to Dana and Sir Archibald Geikie, should be considered as extending to the present time. With this definition, the Quaternary era may comprise 100,000 years, more or less. Judging from the comparative changes of marine molluscan faunas, the Tertiary era was probably twenty to forty times as long, comprising, therefore, some two to four million years; and according to Professor Dana's time ratios of this and the earlier eras, the whole of the history of the earth's fossiliferous rocks may be somewhere between thirty and sixty million years. This estimate lies between that given for the earth's age from physical data many years ago by Sir William Thomson (now Lord Kelvin), namely, 100,000,000 years, and that recently deduced by Mr Clarence King from similar but more detailed investigations, which is 24,000,000 years.



MAP OF NORTHWESTERN CALIFORNIA AND SOUTHWESTERN OREGON

Scale

16 8 0 16 32 MILES

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CRETACEOUS AND EARLY TERTIARY OF NORTHERN CALIFORNIA AND OREGON*

BY J. S. DILLER

(*Read before the Society December 30, 1893*)

CONTENTS

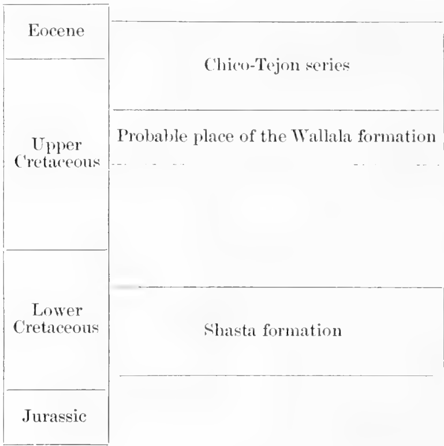
CRETACEOUS.

The Areas and Problems investigated.—In northwestern California and southwestern Oregon, where the Sierra Nevada, Cascade and Coast ranges meet, there is a plexus of mountains which may for convenience be called the Klamath mountain group. The Klamath mountains extend from the fortieth to near the forty-fourth parallel, and include the Yallo Bally, Bully Choop, South Fork, Trinity, McCloud, Scott and Salmon mountains of California, and the Siskiyou, Rogue river, and perhaps others in Oregon. The outline of the Klamath mountain group is indicated on the accompanying map by a heavy broken line. The map (plate 4) contains nearly all the localities mentioned in this paper.

* Printed by permission of the Director of the U. S. Geological Survey.

* This paper is a sequel to a memoir on the geology of the Taylorville region of California, published in Bull. Geol. Soc. Am., vol. 3, pp. 369-394 Both are accompanied by paleontologic papers; the first by Professor Hyatt, on the "Jura and Trias at Taylorville, California" (vol. 3, pp. 395-412), and this one by Mr Stanton's brochure "On the Faunas of the Shasta and Chico Formations," which immediately follows.

In his excellent correlation paper on the Cretaceous,* Dr C. A. White has given a bibliography and concise review of the work already done on the rocks of that system in the Pacific border region from California to Alaska. The present state of knowledge, so far as California is concerned, may be most clearly expressed by the following tabular view, which I copy from Dr White: †



He considers the Chico-Tejon to be the upper portion of the upper Cretaceous, and that it continues upward into the Eocene. The Shasta formation, which is composed of the Horsetown and Knoxville beds, is confined wholly to the lower Cretaceous. There is supposed to have been a long time interval ‡ between the deposition of the Shasta and the Chico-Tejon, and the final portion of this interval is supposed to be represented by the Wallala formation.

My first object in this paper is to adduce evidence in support of the following propositions:

1. The Cretaceous strata of northern California and Oregon, embracing the Chico, Horsetown and Knoxville beds, are an essentially conformable and continuous series of sediments, formed without distinct interruption.

2. These strata were deposited while the region was gradually subsiding and the sea was transgressing northern California and Oregon.

* Bulletin 82, U. S. Geological Survey, 1891.
† Ibid., p. 241.
‡ Ibid., pp. 189, 190.

This subsidence continued until the sea reached the western base of the Sierra Nevada and all or nearly all that part of California north, northwest and west of Lassen peak, and almost the whole of Oregon was beneath its waters.

Relation of the Chico and Wallala Beds.—The Wallala group of Becker and White, exposed at Wallala, Mendocino county, California, and Todos Santos bay of Lower California, has furnished a fauna containing only ten reported species. The characteristic fossil of this formation, *Coralliochama orcutti*, has since been discovered at San Diego, California, and has been studied in the field by Dr W. H. Dall, who informs me that in the same conformable series of strata with the Wallala fauna he found Chico fossils. There is such an intermingling of Wallala and Chico forms that it is not practicable to separate the Wallala and Chico beds. It is the opinion of Dr Dall, which I am permitted to announce, that the Wallala formation may properly be regarded as a phase of the Chico.

In a collection of fossils made in 1888 at Stinking canyon, seven miles southeast of Stillwater post-office, Shasta county, California, there are three fragments, which were then supposed by the writer to be coral. Mr Stanton has examined these specimens and recognizes them as either Rudistæ or Chamidæ. The structure is very well marked, but the fragments are not large enough to give more than the structure. It is so characteristic a feature of these families that there can be little doubt as to its identity. Furthermore, as *Coralliochama orcutti* is the only species yet found in the Cretaceous of the Pacific states that has the peculiar cellular shell structure, it is probable that the fragments in question are of that species. This view of the case is corroborated by the fact that *Axinea veatchii* is one of the most common shells of the Chico beds of that region, and Dr Dall reports the same species, as well as *Baculites chicoensis*, at San Diego. It is evident, therefore, that the Wallala beds are part of the Chico and require no further special consideration.

Relation of the Chico and Horsetown Beds.—Both of the formations are well exposed in Tehama and Shasta counties, California, along the western side of the Sacramento valley. In 1888 and 1889 nine sections were examined and two measured by Mr J. Stanley-Brown and the writer* across the Cretaceous belt between Paskenta and Redding.

The general strike of all the Cretaceous rocks in this belt is approximately north and south, and their dip is to the eastward, away from the older rocks of the Yallo Bally mountains of the Klamath group. Several small faults and folds, beside numerous irregularities in the dip and strike of the strata at other points, were observed, but the irregularities were always slight and of limited extent, and occur irregularly distributed

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* Am. Jour. Sci., vol. xl, Dec., 1890, p. 476.

throughout the whole series. No definite discordance could be made out anywhere within the sections, and the slight irregularities could not be identified in any two sections at the same horizon. There is good reason, therefore, for believing that these irregularities are only local. They are believed to be simply those of original continuous deposition coupled with others that naturally arise in the deformation of a great thickness of shales conformably interstratified with a much smaller proportion of relatively thin conglomerates and sandstones.

The conclusion derived at that time from a study of the stratigraphy alone was that the Cretaceous formations from the base of the Knoxville through the Horsetown to the top of the Chico form a continuous series of sediments, the deposition of which took place without a marked interruption of any kind. At the same time it was fully recognized that even absolute conformity* does not necessarily indicate uninterrupted sedimentation, and that faunal continuity is essential to complete the demonstration. Furthermore, Dr Becker reports an unconformity between the Chico and Shasta groups at several points on the Coast range, and considers it of great importance.† Mr H. W. Turner states‡ that sections north of mount Diablo apparently show continuous deposition from the Neocomian to the Pliocene, inclusive. Nevertheless, from his own observation, there and elsewhere, together with those of Mr Becker and Dr White, he regards it as practically certain that there is an unconformity between the Chico and Knoxville beds.

In none of the cases noted above have the authors been advantagously situated to compare the faunal relations of the two groups. This I shall now proceed to briefly consider.

During the seasons mentioned many Cretaceous fossils were collected from seventy-nine different localities in California and Oregon. Since that time the collections have been greatly augmented from other localities in Oregon by Mr W. Q. Brown, and in California by James Storrs and the writer.

The fossils were all determined by Mr T. W. Stanton‖ under the supervision of Dr C. A. White. They kindly furnished notes on the age of the fossils in each case, distinguishing only between the Shasta and the Chico-Tejon. In some cases, of course, the age could be stated; in others it was doubtful, but in most cases it was given without reservation.

When an attempt was made to represent these determinations on a map and draw the line between the Chico-Tejon and the Shasta, a serious

* McConnel describes the Cretaceous as perfectly conformable on the lower Carboniferous or upper Devonian. Geol. Survey of Canada, Annual Report, 1886, part D, p. 17.

† Bulletin 19, U. S. Geol. Survey, 1885, p. 12; U. S. Geol. Survey Monograph xiii, 1888, p. 188.

‡ Bull. Geol. Soc. Am., vol. 2, pp. 399-401.

‖ Recently Mr Stanton has carefully revised his earlier determinations.

difficulty was encountered, due to the intermingling of the localities. Chico fossils were found in the vicinity of Ono, on the North fork of Cottonwood creek, and elsewhere, close to the base of the Horsetown beds. Their presence in such positions, associated with well recognized Shasta fossils, cannot be satisfactorily explained by attributing it to the deformation of the strata in which they are contained.

A review of the literature, including notes on recent collections concerning the faunas of the Chico and Shasta formations, respectively, in northern California, shows that these faunas are much more closely related than formerly supposed.

Gabb reports* that *Ammonites batesii*, Gabb, *A. remondii*, Gabb, and *Ancyloceras* (?) *lineatus*, Gabb, have been found in both the Chico and the Shasta groups. Dr. White † adds, with some doubt, *Ammonites stoliczkanus*, Gabb. To this small list may now be added the following species:

Actæonina pupoides,	Gabb.	*Trigonia leana*,	Gabb.
Amauropsis oviformis (?)	"	" *equicostata*,	"
Ammonites hoffmanni (?)	"	*Panopæa concentrica*,	"
Arca breweriana,	"	*Cuculæa truncata*,	"
Cardium translucidum,	"	*Cardium annulatum*,	"
Cordiera mitræformis (?)	"	*Corbula traskii*,	"
Hamites vancouverensis,	"	*Mytilus quadratus*,	"
Meekia radiata,	"	*Leda translucida*,	"
" *sella*,	"	*Meekia navis*,	"
Pecten operculiformis,	"	*Tellina matthewsonii*,	"
Ringicula varia,	"	*Chione varians*	"
Straparollus paucivolus (?)	"	*Mactra ashburneri*,	"
Trigonia evansana,	Meek.	*Tellina hoffmanniana*,	"
" *tryoniana*,	Gabb.		

Besides the twenty-five species definitely determined there are six whose identification is doubtful. Of the latter it may be said that, if not identical with the species named, they are most likely closely related. If these identifications are correct there are thirty-one species which continue from the Horsetown beds over into the Chico. Furthermore, in addition to these there are numerous genera common to both series, but not represented, so far as yet known, by determinable common species.

The intermingling of Shasta and Chico fossils in the same beds may be seen best at Horsetown and Texas springs,‡ where those noted in the

* Geol. Survey of California: Paleontology, vol. ii, 18—, pp. 211–213.

† Bulletin 15, U. S. Geol. Survey, p 19.

‡ Texas springs are on the northern side of Clear creek, three miles below Horsetown, Shasta county, California. At these two localities there are not more than 100 feet of Cretaceous rocks exposed, resting directly, with marked unconformity, on fossiliferous Jura-Trias and older rocks.

following lists have been collected recently for the writer by James Storrs. To distinguish the Shasta and Chico species, as indicated by Mr Stanton in these lists, the former have been marked with an asterisk (*) and the latter with an obelisk (†).

FOSSILS FROM HORSETOWN.

Ammonites hoffmanni, Gabb.
**Ammonites breweri*, "
**Deptychoceras lævis*, "
Ancyloceras (?) lineatus, "
**Belemnites impressus*, "
Liocium punctatum, "
Cumlia, sp. undet., "
**Lunatia avellana*, "
†*Ringicula varia*, "
†*Panopæa concentrica*, "
†*Cucullæa truncata*, "
†*Arca breweriana*, "
†*Trigonia æquicostata*, "
Trigonia, related to *evansana*,‡
†*Pecten operculiformis*, Gabb.
†*Cardium (Lævicardium) annulatum*, Gabb.
†*Corbula traskii*.
†*Mytilus quadratus*, Gabb (?)
†*Leda translucida*, "
**Pleuromya lævigata*, Whiteaves.
Rhynchonella, sp. undet.
†*Nemodon vancouverensis*, Meek.

FOSSILS FROM TEXAS SPRINGS.*

**Ammonites hoffmanni*, Gabb.
**Ammonites breweri*, "
Actæonina californica, "
Gyrodes, sp. undet.
**Belemnites impressus*, Gabb.
Liocium punctatum, "
Fusus aratus, "
**Lunatia avellana*, "
Scalaria albensis (?), D'Orb.
**Ringinella polita*, Gabb (?).
**Anisomyon meekii*, "
†*Arca breweriana*, "
†*Trigonia æquicostata*, "
Trigonia related to *evansana*,‡
†*Pecten operculiformis*, Gabb.
†*Trigonia leana*, "
†*Corbula traskii*.
†*Tellina hoffmanni*, Gabb.
†*Mactra ashburneri*, "
†*Chinone varians*, "
Rhynchonella, sp. undet.
†*Tellina mathewsonii*, Gabb.
†*Meekia radiata*, "
†*Meekia navis*, "
†*Meekia sella*, "
Mytilus lanceolatus, Sowerby (?).
†*Panopæa concentrica*, Gabb.

Concerning this collection Mr Stanton, in his report dated December 17, 1892, says:

"It is evident that all the fossils in both these lists belong to one fauna, and probably to a very limited zone, and they will be so considered in making comparisons with described faunas.

‡ Probably not described.

"This collection leaves no room for doubt that the faunas of the Shasta and Chico groups are so intimately blended that they cannot be separated. Horsetown is a well known Shasta locality, from which the types of some of Gabb's Shasta species were collected, yet in this small collection, containing twenty-one species from this place, ten species belong to the Chico fauna as described by Mr Gabb. Combining the collections from these localities, there are thirty-six species enumerated, of which ten have been described as coming from the Shasta group, eighteen from the Chico group, and eight are doubtful or undecided." *

So far as I have been able to learn, about seventy species and a dozen genera not represented by determinable species have already been recognized in the Shasta series of California. Of these fossils certainly more than one-fourth, and probably nearly one-half, continue upward into the Chico beds, and clearly indicate that the Horsetown and Chico beds are much more closely related than has been supposed.†

When we take into consideration, at the same time, both the stratigraphic and faunal evidence, there can be no doubt that the Horsetown and Chico beds were formed in one period of continuous sedimentation.

Relation of the Horsetown and Knoxville Beds.—In Tehama county, California, where the contact between the Horsetown and Knoxville beds is well exposed, their relation can be studied to great advantage. Along Elder creek, just north of the fortieth parallel, at the eastern base of Yallo Bally, the unaltered fossiliferous Cretaceous strata have an apparent thickness of nearly 30,000 feet.‡ The whole series, including the Chico and Shasta groups, dips eastward away from the Coast range with remarkable uniformity and appears to be one continuous series of sediments from top to bottom without a perceptible interruption. In the lower 19,900 feet its only fossil found is *Aucella*. These sedimentary rocks, the Knoxville beds, are limited below by serpentines resulting from the alteration of peridotitic eruptives such as form a considerable portion of the Klamath mountains and Coast range. In the upper 3,900 feet of the Elder creek section Chico fossils occur abundantly, while in the intermediate 6,100 feet Horsetown fossils have been found. The latter are best exposed in the Bald hills between Paskenta and Lowrey's, where *Aucella* occurs abundantly in the basal portion, associated with *Ammonites batesii*, Trask; *A. ramosus*, Meek.; *A. traskii* (?), Gabb; *Ancyloceras percostatus*, Gabb; *Rhynchonella*, n. sp.; *Siliqua*, sp. undet. Although these fossils were not actually seen together with *Aucella* in the same rock exposure, yet they were seen so near together throughout a great

* See also Mr Stanton's paper which immediately follows, p. 225, et seq.

† It is important to remember in this connection that the collections have been made almost wholly by geologists while studying the stratigraphy, and not by paleontologists who were endeavoring to determine the relations of the faunas.

‡ Am. Jour. Sci., 3d ser., vol. xl, 1890, p. 476. See also Bull. Geol. Soc. Am., vol. 2, p. 207.

thickness of conformable shales and sandstones that the writer regarded them as not only contemporaneous but intermingled and belonging to the same fauna. On Elder creek, therefore, the evidence clearly indicates that the Horsetown beds are younger than the Knoxville, and that between them there is a stratigraphic and faunal continuity.

Mr Becker and the writer* claimed that at Riddles, Oregon, *Aucella* is associated with ammonites and other forms of Horsetown age. The writer visited Riddles four times, and, in company with Mr Will Q. Brown, examined nearly all of the fossiliferous rocks of that region, but has never been able to obtain *Aucella* and Horsetown fossils from exactly the same exposure. The rocks containing these fossils, however, are so intermingled and related to each other structurally that there can be no doubt that the fossils all belong to the same fauna. The valley of Cow creek is eroded out of a more or less modified synclinal of Cretaceous rocks. The older *Aucella*-bearing strata are upon the sides. The strata in which Horsetown forms are most abundant occur near the middle of the valley, in the immediate vicinity of Riddles, where *Aucella* also occurs. The whole set of strata appears to be conformable.

The following forms have been identified by Messrs White and Stanton in the collections made by Messrs Becker, Brown and the writer near Riddles, Oregon:

Aucella concentrica,	Fisher.	*Pleuromya lævigata*,	Whiteaves.
Ammonites traskii,	Gabb.	*Pecten operculiformis*,	Gabb.
" *batesii*,	"	" *Californicus*,	"
" *breweri*,	"	*Cardita translucidum*,	"
Belemnites impressus,	"	*Arca breweriana*,	"

In northern California the writer has found *Ammonites traskii* and *A. batesii* in the lower half of the Horsetown beds only, *A. breweri* in the upper half of the Horsetown beds, *Pleuromya lævigata*, *Pecten operculiformis* and *Belemnites* throughout the Horsetown beds, and the last two, *Cardita translucidum* and *Arca breweriana*, in both Shasta and Chico beds.†

* Bull. Geol. Soc. Am., vol. 2, pp. 201–207.

† Mr Will Q. Brown, who, under the writer's supervision, mapped a large part of the Cretaceous rocks in Jackson and Douglas counties in Oregon, has recently made an important contribution of new evidence. A collection which he generously made and transmitted at his own expense shows *Aucella* and an *Ammonite* in the same hand specimen, so there can be no doubt concerning their association. Professor Hyatt has examined the specimen, and reports, December, 1892, that "the *Ammonites* could by its external whorls be referred to either of the two groups *Cosmoceras* of the upper Jura or *Hoplites* of the Cretaceous. By digging into the specimen enough of one of the inner whorls was exposed to indicate that the *Ammonites* is one of the *Cryptoceras* groups of *Hoplites*, and probably a true Cretacic species." Professor Hyatt adds that, as he has not yet been able to find any species of this group with an aperture, his opinion stated above is only provisional, but the evidence so far goes to show that one of the forms of *Aucella* occurs with a Cretaceous *Ammonites*. The *Ammonites*, however, is very distinct from anything yet discovered in the Horsetown beds elsewhere. It occurs in the basal portion of the beds which occupy Cow creek valley.

From both stratigraphic and paleontologic points of view, therefore, the evidence strongly supports the opinion that the Knoxville and Horsetown beds in northern California and Oregon are a successive and continuous conformable series of sediments laid down without perceptible interruption.

Since the Knoxville beds pass upward without interruption into the Horsetown beds and the latter in the same way grade into the Chico beds, we arrive at the conclusion contained in the first proposition of the thesis, namely:

The Cretaceous strata of northern California and Oregon, embracing the Chico, Horsetown and Knoxville beds, or, in other words, the Chico and Shasta beds, are an essentially conformable and continuous series of sediments formed without a distinct interruption. For this series Mr Stanton and I have agreed to use the name Shasta-Chico series.

Distribution and Composition of the Shasta-Chico Series.—The distribution of the Knoxville beds in the Coast range south of the fortieth parallel is described, so far as yet known, chiefly by Becker, Turner and Fairbanks in a number of papers.* They are well developed on Elder creek. If we place the upper limit so far up as to include all the *Aucella*-bearing strata, they extend, according to Fairbanks, as far northward as Cold fork, Tehama county, near the Shasta county line. At that point the present writer has observed the Shasta group to rest unconformably upon the metamorphic rocks, and the unconformity is conspicuous.

The Horsetown beds have been definitely recognized only a few miles south of the fortieth parallel, but in the opposite direction they have been traced a long distance. From Elder creek, where they conformably overlie the Knoxville beds, they extend northward far beyond the latter, unconformably overlapping the older metamorphic rocks, to Horsetown and Texas springs, nearly as far north as Redding.

This overlapping is well shown in the Horsetown beds themselves. *Ammonites ramosus* and *A. batesii* were found on the South fork of Elder creek near *Aucella* and in conformable strata far beneath the latest strata containing *Aucella*. The writer has not found these ammonites to extend above the middle portion of the Horsetown beds. In the vicinity of Ono, on the North fork of Cottonwood, they are common near the unconformable contact between the Cretaceous and metamorphic rocks, but have not yet been discovered as far north so Horsetown, where only the upper members of the Horsetown beds occur. *Ammonites hoffmanni* and *A. breweri*, which occur at Horsetown and farther southward just above

*G. F. Becker: Bulletin 19, U. S. Geol. Survey; U. S. Geol. Survey Monograph xiii; and Bull. Geol. Soc. Am., vol. 2, pp. 201–208.

W. H. Turner: Bull. Geol. Soc. Am., vol. 2, pp. 399-401.

H. W. Fairbanks: American Geologist, vol. ix, p. 159, March, 1892; ib., vol. xi, p. 69, February, 1893.

the latest *A. ramorus* and *A. batesii*, belong to the upper half of the Horsetown beds and extend much farther northward in its series, overlapping the older metamorphic rocks.

From the North fork of Cottonwood creek the Horsetown beds extend far westward, crossing the range between Yallo Bally and Bully Choop mountains along the Hay fork road, and an isolated fossiliferous area of them nearly five square miles in extent occupies Redding creek basin in Trinity county, at the northwestern base of the Bully Choop mountains. Everywhere beyond the limit of the Knoxville beds the Horsetown beds rest, with a marked unconformity, directly on the metamorphic rocks.

The Chico beds have a wide distribution in southern California, and to the northward underlie the Sacramento valley, with outcrops on both sides. At Elder creek, on the western side of the valley, the Chico beds rest conformably on the Horsetown beds. They extend northward, holding the same relation to the Horsetown beds until near Redding, where the Horsetown beds run out and the Chico beds rest unconformably on the metamorphic rocks. This unconformable contact between the Chico beds and older metamorphic rocks, including at least Carboniferous, Triassic and Jurassic strata, has been traced around the northern end of the Sacramento valley, and, by way of the Great bend of Pit river, Mount Shasta, Henley and Ashland, far into Oregon. There is good reason for believing that the Chico beds which extend beneath the lavas of the southern portion of the Cascade range connect with those recognized on Crooked river, Oregon.*

At a number of places in the Klamath mountains there are remnants of Cretaceous rocks in which these mountains were once enveloped, but this covering has nearly disappeared by erosion. To enter into the details of their distribution would lead beyond the proper limits of this paper. Let it be sufficient to say that their distribution shows that the Klamath mountain region was almost, if not wholly, beneath the sea during the closing days of the Cretaceous.†

On Elder creek, in Tehama county, California, the Chico, Horsetown and Knoxville beds are all present. The Knoxville beds extend from this place only a few miles to the northward; the Horsetown beds extend beyond them in that direction at least 25 miles, while the Chico beds stretch still further in the same direction far into Oregon. The Cretaceous section thins out rapidly in the same direction by the successive dropping out of the earlier beds. On Elder creek the Cretaceous is apparently over 20,000 feet thick, at Ono 8,800 feet, and further northeast-

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* Bulletin 33, U. S. Geol. Survey p. 19.

† Since the paper on the geology of Lassen peak was written (Eighth Ann. Rept. U. S. Geol. Survey, p. 411, 412) the subsidence has been found much greater than was at first supposed, so that the Cretaceous island may have wholly disappeared near the end of that period.

ward still less. In none of the sections, however, has the exact top of the Cretaceous been seen. Since these beds are all marine and form one continuous series of sediments, it follows, from their distribution, that during their period of deposition the sea was transgressing what is now the northern portion of California.

That the sea was transgressing during the Cretaceous is clearly shown also by the character of the Cretaceous sediments. Before the deposition of the Shasta group the Klamath mountains, composed of Jurassic, Triassic and Paleozoic rocks, more or less metamorphosed, had been dry land, exposed to weathering for a sufficiently long time to allow the secular disintegration of a mass of surface rock to form the residuary deposits which have become the sediments of the Shasta group. In some cases the deposits of the Shasta group bearing fossils rest upon the residuary deposits and rotten rock from which they were derived, and the line of contact is not easily recognized. This is the case on the southeastern border of the Klamath mountains, in Shasta county, California, between Ono and Igo, where micaceous sandstone at the base of the Shasta group so closely resembles the rotten diorite on which it rests that until the presence or absence of fossils is determined one is in doubt which rock he may be examining.*

Near at hand, too, by the present streams, there are coarse shore conglomerates, including the gravels of the Cretaceous streams which flowed down from the Klamath mountains on the northwest into the ancient bay of the Sacramento valley, and one is surprised to find some evidence that the valleys of the embouching streams of early Cretaceous times are still occupied by streams. This may be true to a very limited extent, but it is noticeable in the upper tributaries of the North Fork of Cottonwood creek near Ono.

From this point the Cretaceous rocks extend westward, and the later members of the series lap up over the Yallo Bally and Bully Choop ridge, the main divide of the Klamath mountains, crossing to the western slope, where they appear well characterized by fossils in Redding creek basin of Trinity county. In all cases the Cretaceous sediments immediately in contact with the metamorphic rocks are of local origin. When they are coarse the contact is plain and the unconformity so well pronounced as to be beyond question, but where the sediments are fine there may appear to be a gradual transition from the older metamorphic rocks to the Cretaceous. For reasons already given, however, I am fully convinced that in northern California and Oregon it is chiefly apparent and rarely if ever real.† It would be expected that the unconformable

* See observations by Dr Dawson in Geol. Survey of Canada, Rept. of Progress, 1877–78, p. 106 B. He describes the same sort of phenomena at the base of the Cretaceous on the Skagit

† In cases where the Cretaceous strata have been metamorphosed a transition from the unaltered to the altered portions without an intervening unconformity would be expected.

contact immediately underneath the Knoxville beds would be less conspicuous than that between the Horsetown beds and the metamorphic rocks or between the Chico and the metamorphics. This would follow from the fact that the Knoxville beds, having been deeply buried by later sediments, were subjected to more intense metamorphic action, which tends to render the original contact less evident.

In Siskiyou county, California, upon the eastern slope of the Klamath (Scott) mountains, adjoining Shasta valley, there are a number of important exposures of Cretaceous rocks. Dr D. Ream, of Yreka, kindly furnished me a section of the rocks penetrated by Mr King's well at the salt works in Shasta valley, where over 500 feet of fossiliferous sandstone was observed beneath the lavas of Shasta valley. The same rocks are exposed at the surface near Yreka and on Willow creek, where they contain Chico fossils. On the edge of Shasta valley the Cretaceous strata dip to the eastward and lap up over the lower slopes of the Klamath (Scott) mountains, which lie upon its western border. The tilting evidently occurred at the time the Klamath mountains were upheaved, and the unconformably overlapping Cretaceous strata have since been nearly all eroded. A few conspicuous remnants, however, are still there to tell the tale. The best of these are at Cave rock, three miles north of Gazelle, and near the summit on the road from Yreka to Fort Jones. The last is at an elevation of 2,000 feet above Shasta valley and over 5,000 feet above the sea. The mass is about 400 feet in thickness, and the conglomerate at its base is composed chiefly of white quartz and unassorted angular fragments of schistose rocks like those in place near by. Although fossils were not found at either of these localities, there can be scarcely a doubt that they represent the overlapping Cretaceous strata from the foot of the same slope.

In Douglas county, Oregon, along Olalla creek, slates have been found containing *Aucella* alone, and the rocks are considerably metamorphosed. At Buck mountain, a few miles further southeast and twelve miles west of Riddles, *Aucella* occurs alone in coarse, pebbly sandstone, which has a slightly metamorphic aspect. This appearance, however, is due not so much to actual metamorphism since deposition as to the fact that the rock is composed chiefly of residuary material removed but a short distance from its original position; consequently its contact with the older metamorphic rocks is not sharply defined. The same is true at some localities, but not all, about Riddles, in the valley of Cow creek, where both *Aucella* and Horsetown fossils occur in abundance. Still further eastward, on Grave creek, an area of Shasta beds occurs. *Aucella* is absent, and there are some Chico forms present, with those of the Shasta group, so that the horizon must be near the top of that group. These

fossiliferous strata are in part coarse conglomerates of local origin and, according to the observations of Will Q. Brown, as well as of the writer, are clearly unconformable to the metamorphic rocks.

Twelve miles further in an easterly direction, near Jacksonville, and elsewhere in Jackson county, Oregon, the Chico rocks, now called Horsetown by Mr Stanton, rest directly with a marked unconformity on the metamorphics.

In Oregon, therefore, the evidence, although less complete, is entirely in harmony with that of northern California, and we are led to the conclusion stated in the second proposition of the thesis, namely: While the Shasta-Chico series was being deposited the region was gradually subsiding and the sea transgressing to the eastward in northern California and Oregon. This subsidence continued until the sea reached the western base of the Sierra Nevada, near the fortieth parallel, and all or nearly all that part of California north, northwest and west of Lassen peak, as well as almost the whole of Oregon, was beneath its waters.

The occurrence of the Cretaceous in Washington, excepting that on Sucia, Orcas and Ship Jack islands, near Vancouver, has hitherto been a matter of considerable doubt. Its determination has been based largely upon certain casts which were supposed to have been of *Baculites*. According to Willis,* the Cretaceous of northwestern Washington is comparatively thin and rests directly on metamorphic rocks, which are pre-Cretaceous and probably of Paleozoic age.

While in Seattle I obtained from Mr E. W. P. Guye a well-preserved *Baculite*, which Mr Stanton determined as *Baculites chicoensis*. It was obtained on the Snoqualmie river, three miles below the falls, and shows the presence of the Chico at that point. The rock is unaltered and lies between the Puget group and the metamorphics.

At the same time my attention was called to a bowlder found in Seattle; it is composed chiefly of *Aucella* and was in all probability transported from the Cascade range. The rock is unaltered and closely resembles some of the *Aucella*-bearing rock about Riddles.

In the collection of Professor T. Condon at the state university, Eugene, Oregon, there is a large fragment of rock † containing a multitude of robust shells of *Aucella*. It came from Vashon island, near Tacoma.

Dr Dawson ‡ reports *Aucella*-bearing rocks on the Skagit north of the international boundary. It is believed that they extend south into Washington and have furnished the bowlders referred to.

There can be no doubt that the Shasta-Chico series is represented in

* Tenth Census, vol. xv, 1886, p. 761.

† This is probably the same material that Becker and White refer to in U. S. Geol. Survey Monograph xiii, pp. 202, 232.

‡ Geol. Survey of Canada, Report of Progress, 1877–78, p. 106 B.

the Puget sound region, but of its extent scarcely anything is known. Further northward, however, the same series is extensively developed in Vancouver and Queen Charlotte islands, as well as within the interior portion of British Columbia, where it has been described by Dr Selwyn, Dr Dawson, and Mr Richardson in the reports of the Canadian geologic survey. From an extensive knowledge of the facts, Dr Dawson concludes that in early Cretaceous times the immediately post-Triassic elevation had been followed by a subsidence of the land, resulting in the reoccupation by the open sea of a great area near the Pacific coast and north of the fifty-fourth parallel, spreading eastward in a more or less connected manner completely across the present position of the Cordilleras. The Gold ranges, and probably also many other insular areas, continued to exist as dry land. As local terrestrial conditions are recurrent throughout a great thickness of strata, it is obvious that the subsidence was continuous or nearly so and was followed *pari passu* by sedimentation.

Dr Dawson says:

> "About the stage in the Cretaceous which is represented by the Dakota group, however, a much more rapid downward movement of the land occurred. This is marked by the occurrence of massive conglomerates, which have been recognized in many places in the southern part of the interior of British Columbia, as well as westward to the Queen Charlotte islands." *

Dr Dawson calls attention to the fact that west of the axis of the Coast ranges the area of Cretaceous sedimentation was transgressively extending southward, the local base of the Cretaceous being found at successively higher stages in the system in that direction, till at a time, which is believed to have corresponded with the Laramie of the plains, the sea invaded the Puget sound region. The invasion of the sea in British Columbia was contemporaneous with that of northern California and Oregon just described, and possibly also with that which carried *Aucella* around the southern end of the land barrier into Mexico.†

Tertiary.

The Tejon beds are now generally regarded as representing the earliest Tertiary deposits of California and Oregon. In middle California these beds are well represented. They are not only conformable with the Chico, but have been considered to form, with the Chico, a continuous series of strata, deposited without any interruption in the process of sedimentation. This is unusual, for generally a faunal and stratigraphic break occurs between the Cretaceous and Tertiary.

* Am. Jour. Sci., 3d ser., vol. xxxviii, 1889, p. 120; Transactions of the Royal Society of Canada, vol. viii, sect. iv, 1890, pp. 8, 9. See also S. F. Emmons, Bull. Geol. Soc. Am., vol. 1, p. 278.

† Neues Jarb. für Min., Geol. u. Pal., 1890, ii band, p. 273.

Lindgren has recognized the Tejon in the Sacramento valley as far northward as Marysville buttes.* In the Coast range Whitney, on Gabb's observation, reports the Tejon nearly as far northward as Round valley, Mendocino county.* Similar coal-bearing strata containing fossil leaves have been observed by the present writer at Hyampome, Cox's bar and Redding creek basin, in Humboldt and Trinity counties, but the evidence that these strata are really Tejon is not convincing; they are rather more probably Miocene. With the exception of the locality at Marysville buttes, no molluscan fossils of Tejon age have been found in northern California, and it has generally been regarded as absent.

In Oregon, however, the case is very different. The Tejon, well characterized by an abundance of marine fossils, is represented by at least 2,000 feet of strata. Professor Condon has reported it at Cape Arago by Coos bay, and at Albany. Dr C. A. White has recognized it at Astoria, where it has since been studied by Dr W. H. Dall. Professor Condon called my attention by letter to an excellent exposure of fossiliferous Eocene on the South fork of the north Umpqua, where Mr Will Q. Brown and the writer have made several collections. At least 1,000 feet of Eocene strata are there exposed. They contain throughout abundant shells of *Cardita planicosta*, with other fossils, and rest directly upon an irregular surface of metamorphic rocks. From this point the Eocene beds have been traced southwestward nearly to Coos bay, and fossils have been collected at Cleveland, Lookingglass, Olalla and Table mountain. At the last two localities they rest on the upturned edges of the Shasta-Chico series. The unconformity at the base of the Tejon group in Douglas county, Oregon, is in some cases conspicuous and in all cases well defined, and it appears that the Shasta-Chico series was not only folded but considerably eroded before the beginning of deposition of the Tejon in that region.

With such a physical break, faunal continuity between the Chico and the Tejon of Oregon could hardly be expected; but, to test this point as far as possible with the collections now at hand, I requested Mr Stanton to carefully examine the collections of Tejon from Oregon and Washington for Chico species. In response Mr Stanton sent lists of all the species collected at a number of localities, and remarks:†

"You will notice that there are a few species among them that have been reported from both the Chico and the Tejon. For example, *Pholadomya nasuta*, *Cylichna costata* and *Turritella chicoensis*. There are also some others that closely resemble Chico species, but which I believe to be distinct, such as *Mactra ashburneri* and *Dentalium stramineum*. We have the two species last named from Chico localities, and, on direct comparison with the related Tejon forms, there is no difficulty

*Geol. Survey of Cal., Pal., vol. ii, p. xiii.

† January 9, 1893.

in pointing out recognizable differences. None of the other doubtful species are represented in any of our collections from Chico localities.

"It is therefore safe to say that your collections do not show any commingling of the Chico and Tejon faunas, and I may add that, so far as I have examined them, none of the other collections in the National Museum show such blending." *

All of the facts yet known indicate that in Oregon and northern California there is a faunal and stratigraphic break between the Chico and the Tejon.

Pre-Cretaceous Elevation of the Klamath Mountains and Sierra Nevada.

The existence of a large land area in northwestern California and southwestern Oregon in early Cretaceous times is clearly indicated by the composition and distribution of the Cretaceous rocks of that region. The geologic date of the uplift must have been considerably earlier than the beginning of the Shasta-Chico epoch in order to allow the secular disintegration of the surface rocks to furnish the Cretaceous sediments for the invading sea.

Since the writer's paper on the geology of the Taylorville region was published, our knowledge of the distribution of the Jura-Trias and Carboniferous in northern California has been considerably extended, and, as this distribution has an important bearing on portions of this paper, it is necessary to record it here.

A large number of fossils were collected by the writer and James Storrs on and near Pit river by the western arm of the Great bend, and at many places near Cedar creek and Halcombs, on the toll and stage roads between Redding and Burney valley. The areal geologic work done at that time is shown in the Bend and Cedar formations in the northwestern corner of the Lassen peak atlas sheet, a preliminary edition of which is now in proof. The fossils were all examined by Professor A. Hyatt, and in the descriptive text accompanying that sheet his conclusions concerning the age of the rocks are stated. Both the Jurassic and Triassic of the Taylorville region are well represented in Pit river valley and add another strong argument, showing that the Klamath mountains of northwestern California are composed in large part of the same rocks as the Sierra Nevada. †

Along the western side of the Sacramento valley, near the basin on the Humboldt trail eight miles west of Pettyjohns, in Tehama county,

* Almost thirty species have been identified from the Tejon of Oregon and Washington.

† Mr Harold W. Fairbanks, who has published an article entitled "The pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Range" (Am. Geologist for March, 1892, vol. ix, pp. 153–166; also for Feb., 1893, vol. xi, pp. 69–81), kindly called my attention to a number of new localities in the Pit river region from which he had recently collected fossils.

fossils were found in a limestone. Mr Walcott, who examined the fossils for me, reported that only one genus, viz, *Chætetes*, could be identified, and from what is known of the rocks of that region he refers the limestone to the Carboniferous. This horizon had long been known further northward, near Bass' ranch, through the investigations of Trask and Whitney.

Pentagonal and round crinoid stems have been discovered by James Storrs in a limestone on Clear creek between Horsetown and Texas Springs. Professor Hyatt regards them as Triassic and probably of the same horizon as the Hosselkus limestone.

At Texas Springs Mr Storrs found a limestone containing a large pentagonal crinoid stem, a spirifer and other brachiopods which Professor Hyatt regards as belonging within the Jura-Trias. The older rocks, upon which the Cretaceous strata of the western and northern borders of the Sacramento valley at the Pit river region rest with a conspicuous unconformity, are at least in part Jurassic, Triassic and Carboniferous in age.

As bearing upon the general distribution of the Taylorville Jurassic, a collection of fossils made by Professor Condon on the upper waters of Crooked river, in the Blue mountains of Oregon, deserves mention. In lithologic character and fossils Professor Condon's specimens appeared to the writer to very closely resemble the Jurassic rocks of Taylorville. Professor Condon kindly loaned the specimens to be sent to Professor Hyatt, who confirmed this view and established another important locality of Taylorville Jurassic.

The discovery of Jurassic fossils on Pit river synchronous if not identical with that of Taylorville has thrown new light on the pre-Cretaceous elevation of the Klamath mountains and the Sierra Nevada. Concerning some of these fossils Professor Hyatt says* they " include the same association of forms as the Mormon sandstone fauna, and, although the specimens are not all well preserved, I have little doubt that the rocks from which they came were synchronous with the Mormon sandstone of Taylorville."

These Jurassic rocks were deformed and metamorphosed with the Triassic, Carboniferous and other portions of the auriferous slates. They are separated from the unaltered Cretaceous (Shasta-Chico series) of that district by a conspicuous unconformity. The same unconformity extends southwestward, by way of Redding, Horsetown and Ono, along the western side of the Sacramento valley, into Tehama county, California, and northward, by way of Yreka, Cottonwood creek and Ashland, far into Oregon. It is evident, therefore, that a great upheaval and met-

* Letter of October 4, 1892.

amorphism of the Klamath mountains and Sierra Nevada occurred soon after the close of the Taylorville Jurassic.

How long a time interval is represented by the great unconformity between the Taylorville Jurassic and the Shasta-Chico series is not yet known, but that the upheaval took place in the earlier part of the interval is most probable.

The relation of the Mariposa beds to the Taylorville Jurassic, on the one hand, and to the Shasta-Chico series, on the other, is yet a matter of doubt, but will soon be resolved by Mr Becker and his assistants, Messrs Turner and Lindgren, who are now making a thorough survey of the Gold belt of the Sierra Nevada. It is already evident from the researches of Mr Becker and Dr White that the faunas of the Mariposa and Knoxville beds are closely related, and on this account the great faunal and stratigraphic break corresponding to the great unconformity between Shasta-Chico series and the Taylorville Jurassic on Pit river might be expected at the base of the Mariposa beds. That an upheaval occurred at the close of the Jurassic of Taylorville is indicated by the distribution of *Aucella* in northern California and Oregon. Accordingly the disturbance in the Mariposa beds would have to be referred* to a later epoch, either within the *Aucella*-bearing series or to the close of the Chico or Miocene.

Inter-Cretaceous-Tertiary Upheaval of the Klamath Mountains.

The lower portion of the Shasta-Chico series is in general more disturbed than the upper or Chico portion. This is due to various causes, the principal of which is to be found in the fact that, as now exposed, the Shasta beds are nearer the centers of disturbance than the Chico. The Chico has been removed from the disturbed areas by erosion.

On the western side of the Sacramento valley, along Elder creek, where the Shasta-Chico series is exposed, the whole series is tilted, but the Shasta beds in the western portion toward the Coast range are somewhat more disturbed than the Chico beds in the eastern portion; yet the difference is not great and the change so gradual through a number of miles of well-exposed strata that we looked in vain for any break in the stratigraphy or fauna.

The character of the strata had much to do in determining the amount of deformation. The shales of the Shasta-Chico series are generally more deformed than the sandstones and conglomerates of the same locality, because less rigid. They predominate in the lower portion of the Shasta-

*See paper by Mr S. F. Emmons "On Orographic Movements in the Rocky Mountains," Bull. Geol. Soc. Am., vol. 1, p. 279.

Chico series, and were deeply buried beneath the Chico. As a consequence they were subjected to the more rigorous action of deforming forces. The Shasta-Chico series in northern California and Oregon is rarely vertical, and from that angle the dip ranges to nearly horizontal. The gentlest inclinations are in the Chico on the western side and around the northern end of the Sacramento valley, and always miles away from the disturbed lower portions of the same series.

The geologic date of the disturbance next succeeding the pre-Cretaceous one just referred to is well marked in Oregon, where, as already described, the Tejon is unconformable upon the Shasta-Chico series. Near the unconformable contact the Tejon is not folded, so that the deformation of the Shasta-Chico series, which is conspicuous in that region, took place before the deposition of the Tejon, or about the close of the Cretaceous. That this deformation was accompanied by upheaval is shown by the absence of Tejon in northern California and part of Oregon.

This deformation and upheaval appear to have been of great extent to the northward, for the Cretaceous sea which once covered part of Oregon, Washington and a large portion of British Columbia was driven westward by it, in some cases beyond the present limit of the continent; and about this time, according to King, the Wasacht range was uplifted.*

Résumé and Conclusions.

The observations of Dr W. H. Dall have shown that the Wallala beds are a phase of the Chico and belong near the base of those beds, essentially in the position assigned to them by Dr White.

The Chico and Horsetown beds, which were once supposed to be separated by a long interval, are now known to be stratigraphically and faunally continuous, and are the result of an uninterrupted epoch of sedimentation.

In the same way the Horsetown and Knoxville, which together form the Shasta beds, are shown to be stratigraphically and faunally contin-

*The date of the deformation of the Mariposa beds must yet be regarded as an open question. If, as argued by Mr Becker, later by Mr Fairbanks, and finally by Messrs Turner and Lindgren, who have mapped the region, the Mariposa beds are unconformably beneath the Chico, their deformation would appear to have antedated the deposition of the Shasta-Chico series, for in the group of strata including the Mariposa, Knoxville, Horsetown and Chico beds the argument for faunal and stratigraphic continuity is weakest between the Mariposa and Knoxville beds. The faunal relation of the Mariposa and Knoxville beds, however, is so close, according to Mr Becker, as not to admit of a great physical break between them. If one exists it is possibly local and of limited extent. This might still be in accord with the facts observed in northern California and Oregon, where no break has yet been observed within the *Aucella*-bearing rocks.

Numerous observers have called attention to the great mountain-forming epoch about the close of the Miocene. During that revolution the Klamath mountains and the Sierra Nevada were modified to a large extent. The geologic history referred to in this paper wholly precedes that disturbance.

uous, and it follows that the Shasta-Chico series is the result of continuous sedimentation.

The distribution of the members of the Shasta-Chico series and the composition of those in contact with the older rocks, on which they rest unconformably, shows that during their deposition the northern parts of California and Oregon were gradually subsiding and the sea transgressing.

In Oregon the Tejon rests upon the Shasta-Chico series unconformably, and the paleontologic evidence, so far as it goes, tends to show that there is a faunal break in that region between the Chico and the Tejon.

At the close of the Taylorville Jurassic there was an upheaval, by which the Klamath mountains and the northern end of the Sierra Nevada were outlined and the land extended far northwestward into the Pacific.

This upheaval was followed after a considerable interval by a subsidence, which brought in *Aucella* from the northwest and inaugurated the Shasta-Chico series.

In northern California and Oregon the subsidence continued throughout that series, unless interrupted between the Mariposa and Knoxville epochs, and was brought to a close by another mountain-forming upheaval, which forced the sea far to the westward before the beginning of the Tejon.

U. S. Geological Survey,
Washington, D. C.

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ON THE GEOLOGY OF NATURAL GAS AND PETROLEUM IN SOUTHWESTERN ONTARIO

BY H. P. H. BRUMELL

(Read before the Society December 29, 1892)

CONTENTS

The Areas under Consideration.

Gas-producing Area.—In that part of Ontario lying south and west of a line drawn from Toronto to Collingwood, operations in search of gas and petroleum have been carried on for a number of years. They have resulted in the discovery of two gas-producing areas of considerable extent, viz. that in Essex county, in the vicinity of Kingsville and Ruthven, and that in Welland county, in the neighborhood of Sherkston. Nor are the wells of these two fields the only producing ones, for many isolated borings, such as those at Cayuga, Dunnville and Mimico, afford no inconsiderable flows.

Oil-producing Area.—Petroleum has unfortunately been found in commercial quantities in but one county, that of Lambton, where there are two distinct pools, known as the Oil Springs and Petrolea fields. These pools have been drawn upon continuously since 1862, when the first flowing well was struck, in what is now known as the "upper vein." Following closely upon this discovery were more extended operations, which brought to light the present oil horizon, known as the "lower vein." The upper vein having long been exhausted, the source of supply has for years been in the lower, wherein wells affording as much as 7,500 barrels per day have been sunk.

Authorities indicated.—As I wish to treat more of the geologic than the historical side of the question, I will follow out the title of my paper, but before doing so cannot do better than refer those interested in the oil industry in Ontario to Dr Robert Bell's paper on "The Petroleum Field of Ontario," published in volume v, Transactions Royal Society of Canada, and to the report of the Division of Mineral Statistics and Mines, part S, Annual Report Canadian Geological Survey, volume iv, 1888–89.

Geologic Section of the Areas.—There is in that part of the province under consideration a series of rocks, lying in almost undisturbed position, ranging from the Trenton to the Portage formation, with an approximate total thickness of 4,100 feet, as follows:

	Formations.	Approximate thickness in feet.	Average thickness in feet.
Devonian	Portage and Chemung	25– 200	100
	Hamilton, about	350	350
	Corniferous	160– 300	230
	Oriskany	6– 25	15
Silurian	Lower Helderberg, Onondaga	300–1,000	650
	Guelph	140– 160	150
	Niagara	100– 130	115
	Clinton	30– 150	90
	Medina	600– 800	700
Cambro-Silurian	Hudson River	500– 900	700
	Utica	300– 400	350
	Trenton, Black River	600– 750	675
	Total		4,125

The geologic Formations involved.

Detailed Description essential.—To meet the requirements of this paper it is perhaps better to describe, so far as is known, the various formations in descending order.

Portage.—The Portage in Ontario consists of a series of fissile black bituminous shales and is developed almost altogether in the county of Lambton, where it acquires, according to Dr T. Sterry Hunt, a thickness of 213 feet, as shown in a boring made at Corunna.* These shales in a well bored at Sarnia show a thickness of 80 feet, and again, in a well sunk on lot 12, concession 10, Bosanquet township, they are seen to have a total thickness of 95 feet. In both of these instances it lies immediately over the upper shale bed of the Hamilton formation, the upper limestone bed of which, found at Petrolea and elsewhere, is wanting. In the township of Dawn, and again east of Oil Springs, 70 feet of black shales are found. In this instance they rest upon the upper limestone of the Hamilton. In a syncline lying between Petrolea and Oil Springs, and separating the two fields, 40 feet of black shales are found in a well drilled on Fox creek, the elevation of which is considerably less than that of Oil Springs. These shales in no instance afford oil, but are probably the source of the considerable quantities of shale gas found in the overlying gravel and sand.

Hamilton.—The wells in Petrolea and Oil Springs and the greater number of those drilled in Lambton county show that the black shales of the

* Report of Progress, Geol. Survey of Canada, 1866, p. 247.

Portage group immediately overlie a limestone bed which constitutes the upper stratum of the Hamilton formation. This series of rocks consists of alternating beds of limestone and gray shales (known locally as "soapstone") and has a thickness, according to a drilling made at Kingstone's mills, Lambton county, of 396 feet. Dr Hunt* speaks of this well as being important in showing the thickness in Ontario of the middle and upper Devonian, which, if we add to the 396 feet found here the 213 feet of rocks belonging to the Portage found at Corunna, is 609 feet.

The record of the well at Kingstone's mills is as follows:

Clay	14 feet.
Black shale	50 feet, Portage.
Shales, soft, and limestone	396 feet, Hamilton.
Limestone, hard	44 feet, Corniferous.

At Petrolea the Hamilton is only 296 feet thick, as follows:

Limestone ("upper lime")	40	feet.
Shale ("upper soapstone")	130	"
Limestone ("middle lime")	15	"
Shale ("lower soapstone")	43	"
Limestone ("lower lime")	68	"

At Oil Springs, 8 miles southward, the formation shows evidence of having thinned out, the thickness there being only 240 feet according to the following record of many wells drilled on the eastern side of the field:

Limestone ("upper lime")	35	feet.
Shale ("upper soapstone")	101	"
Limestone ("middle lime")	27	"
Shale ("lower soapstone")	17	"
Limestone ("lower lime") about	60	"

Corniferous.—Underlying the so-called lower lime of the Hamilton is a series of bituminous limestones constituting the Corniferous formation—the source of the oil of Lambton county. Regarding the distribution of this formation in Ontario, the following description is given:†

"The surface occupied by this formation in western Canada is probably between 6,000 and 7,000 square miles. A great part of this, however, is deeply covered with drift, so that the exposures are comparatively few. To the eastward this formation is bounded by the outcrops already assigned to the underlying strata, the limits of which in many parts have as yet been but imperfectly traced. The whole of the province to the west and south of this line belongs to the Corniferous forma-

* Report of Progress, Geol. Survey of Canada, 1866, p. 251.

† Geology of Canada, 1863, p. 362.

tion, with the exception of a belt of higher Devonian rocks which crosses the country from Lake Huron to Lake Erie and divides the region into two areas. These newer strata occupy a saddle-shaped depression in the great Cincinnati anticlinal, which runs nearly east and west through the peninsula, while the course of this depression or synclinal is nearly north and south from Plympton, on Lake Huron, to Orford, on Lake Erie. The belt of higher rocks has a breadth of only about twenty-five miles on the anticlinal between the Thames and Sydenham rivers, but on either side it spreads to the northeast and to the southwest along the shores of the two lakes."

In two wells, those of London and the "Test well," at Petrolea, the Corniferous is shown to have an approximate thickness of about 200 feet, consisting throughout of hard gray limestone. In all wells where this formation has been struck the rocks appear to have been of uniform character and to consist of white or grayish limestones holding nodules and layers of chert.

Oriskany.—The Oriskany formation is but slightly developed in Ontario, being entirely wanting in most of the wells sunk to or beneath its horizon; again, owing to the carelessness of drillers, its presence may not have been noted. In the townships of Oneida and north Cayuga, in Haldimand county, it is exposed and forms beds of sandstone aggregating at the most twenty-five feet in thickness. In many of the records obtained from drillers mention is made of a sandstone at about the summit of the Onondaga, but in most cases close inquiry has proven these statements to be fallible, the so-called sandstone being generally a granular dolomite. However, in two wells at least there is strong evidence of a sandstone occurring at a point near the position occupied by the Oriskany. One of these was a well drilled at Dresden, Camden township, Kent county, wherein the following record was met with, according to the driller:

Surface deposits	43	feet.
Shale, black	180	"
Limestone	12	"
Shale ("soapstone")	172	"
Limestone	75	"
Sandstone	44	"

Again, in a well sunk near Dresden, on lot 3, concession 2, Camden township, the following section was, according to the driller, obtained:

Surface deposits	60	feet.
Shale, black	20	"
Limestone	30	"
Shale ("soapstone")	204	"
Limestone	117	"
Sandstone	46	"

Onondaga and Lower Helderberg.—Beneath the Oriskany, when present, and usually directly underneath the Corniferous limestone, is a long series of limestones, dolomites, marls, shales, gypsum, and salt constituting the Onondaga, which for convenience can be made to include the Lower Helderberg. This formation acquires a thickness, in the salt region of Huron county, of at least 1,500 feet, according to the following very accurate record made by Dr T. Sterry Hunt* of a well sunk at Goderich by Mr Henry Attrill, of that place:

	Feet.	*Inches.*
Surface deposits	78	9
Dolomite, with thin limestone layers	278	3
Limestone, with corals, chert and beds of dolomite	276	0
Dolomite, with seams of gypsum	243	0
Variegated marls, with beds of dolomite	121	0
Rock-salt, first bed	30	11
Dolomite, with marls toward the base	32	1
Rock-salt, second bed	25	4
Dolomite	6	10
Rock-salt, third bed	34	10
Marls, with dolomite and anhydrite	80	7
Rock-salt, fourth bed	15	5
Dolomite and anhydrite	7	0
Rock-salt, fifth bed	13	6
Marls, soft, with anhydrite	135	6
Rock-salt, sixth bed	6	0
Marls, soft, with dolomite and anhydrite	132	0
Total depth	1,517	0

As to what is the greatest actual thickness of the formation it is impossible to say, as data regarding its lower measures are wanting. In none of the records obtained has there been definitely noted the red and greenish shales indicative of the base of the formation in New York state. According to the records of wells sunk for gas in Bertie township, Welland county, it has there a total thickness of 390 feet, consisting of gray and drab dolomites, black shale and gypsum, and in a well at Petrolea it was found to be 905 or more feet thick, as follows:

Limestone, hard, white	500 feet.
Gypsum	80 "
Salt and shale	105 "
Gypsum	80 "
Salt and shale	140 "

The formation may be thicker, as drilling ceased in the salt and shale.

* Report of Progress, Geol. Survey of Canada, 1876-77.

Guelph.—Underneath the Onondaga is met with, over a considerable portion of the province, a series of yellowish to brown and in places bituminous dolomites, having a probable thickness of not more than 160 feet and known as the Guelph formation. These beds have been pierced in many wells in Ontario, but efforts to obtain from drillers definite information as to their thickness and character have been useless, nor has it been found possible to draw any distinction, in records of wells so far obtained, between the dolomites of this formation and the gray dolomite of the Niagara, which immediately underlies it. In the wells of the Bertie township, Welland county, gas field are found about 240 feet of dolomites of Guelph and Niagara age, and in number 1 well sunk by the Port Colborne Natural Gas Light and Fuel company in Humberstone township, Welland county, there are found, according to the driller, 30 feet of shaly dolomite and 188 feet of brown dolomite, with dark-blue shales toward the bottom. In the town of Paris a well was sunk in which 99 feet of Guelph dolomite was found immediately underlying the Onondaga. The boring was not continued beyond this depth, so it is impossible to say what thickness the formation attained at this point.

Niagara.—The Niagara formation, the upper beds of which are composed of dolomites, as stated above, has a probable thickness in Welland county of about 140 feet, made up of gray dolomites reposing upon about 50 feet of dark shale. It extends throughout the province in a northwesterly direction to Cabotshead, where, according to the Geology of Canada, 1863, it would have a thickness of about 450 feet, and is composed of a whitish subcrystalline limestone. On the Welland canal, near Thorold, is seen the following section in ascending order:*

Bluish-black bituminous shale	55	feet.
Bluish-gray argillaceous limestone	8	"
Dark bluish bituminous limestone	8	"
Light and dark-gray magnesian limestone	26	"
Bluish bituminous limestone	7	"
Total	104	"

This section does not include two 10-foot beds of bluish-gray magnesian limestone which may be of Clinton age, though toward their summit holding two species of fossils characteristic of the Niagara series in New York, nor does it reach the summit of the formation. In Essex county the beds met with in the various wells sunk near Kingsville and Ruthven at a depth of from 1,000 to 1,100 feet consist of a light yellowish-gray vesicular dolomite which is probably of Niagara age. It is from this dolomite that the large flows of gas have been obtained.

*Geology of Canada, 1863, p. 322.

Clinton.—The Clinton, on entering Canada through the Niagara peninsula, consists of a band of green shale 24 feet thick underlying 18 feet of limestone, though in the wells of the Provincial Natural Gas and Fuel company in Bertie township the shales are apparently entirely wanting, the formation consisting, it is said, of 30 feet of white crystalline dolomite, which is grayish toward the base. In number 1 well of the Port Colborne company there were found beneath the dark shales, indicative of the base of the Niagara, 72 feet of marls and dolomites, which are in all probability attributable to the Clinton. The formation appears to thicken toward the northwest, gradually diminishing again, as proved by the exposure which trends to the north from Hamilton toward Collingwood, a little south of which it takes a sweep to the westward. In Wentworth county, in the township of Flamborough West, the Clinton is seen to rest upon about 8 feet of whitish sandstone, constituting the "gray band," which is apparently missing in Welland county, but on the northern extension of the formation proves a very conspicuous feature, forming a terrace upon which the shale and limestone of the upper part of the Clinton occur. In the many records of wells drilled in the interior of the province evidence is wanting to estimate the thickness or character of the Clinton, though in one, that of a boring at Waterloo, there were said to have been found 114 feet of blue shale lying immediately above red shale undoubtedly of Medina age. In all probability there have been included in this 114 feet the dark shales of the Niagara.

Medina.—Following immediately upon the Clinton and, where present, the sandstone of the gray band is a great thickness of red and white sandstones and red and green shales which constitute the Medina. This formation has its greatest thickness in the Niagara peninsula, gradually diminishing toward the north, where, at Cape Commodore, in Grey county, there are seen beneath the Clinton limestone 109 feet of red and green shales resting upon strata of the Hudson River formation. In number 1 well, drilled in Port Colborne by the Port Colborne company, the measures penetrated for a distance of 770 feet were—

Red shale, with thin bands of white sandstone	50	feet.
Red and white sandstone	53	"
Soft red shale, with bands of gray and green	667	"
Total	770	"

Drilling ceased at this point at a distance of at least 200 feet above the base of the formation, as in a well on lot 6, concession 15 of Bertie township, there were found 1,000 feet of strata attributable to the Medina. The best record of the upper beds of the formation is that of the bottom

of number 1 well, drilled by the Provincial company, on lot 35, concession 3, Bertie township, and which is as follows:

Red sandstone	55 feet.
Red shale	10 "
Blue shale	5 "
White sandstone	5 "
Blue shale	20 "
White sandstone ("gas-rock")	16 "
Total	111 "

Throughout the gas-fields of Bertie and Humberstone townships this section of the upper beds of the formation appears to be quite constant, only very slight variations being noted. The most marked is that in number 9 well, drilled by the same company, and wherein was found—

Red sandstone	55 feet.
Red shale	10 "
Blue shale	5 "
White sandstone	20 "
Blue shale	12 "
Total	102 "

The second white sandstone bed beneath was penetrated only four feet.

In a well sunk on lot 11, concession 7, Barton township, Wentworth county, and about forty miles to the northwest of the above-mentioned, there were found 595 feet of red shale, with bluish bands, lying immediately above the bluish shales of the Hudson River. Again, a few miles northwest of this place, and at the insane asylum in Hamilton, there were said to have been found 634 feet of red shale, and at Dundas, three miles north of this, in a well sunk in the valley and begun in the Medina, there were found 400 feet of red shale, in both instances resting upon the Hudson River shales. To go back to the eastward again, there were found in a well at Saint Catharines 548 feet of red shale. This does not, however, show the entire thickness of the measures, which in a well at Thorold, eight miles southward, proved to be 930 feet thick, as follows:

Red sandstone	30 feet.
Shale	57 "
Gray sandstone	30 "
Red shale	813 "
Total	930 "

Many other records of wells bored into or through this formation are at hand, which go to show that it varies locally as to thickness, yet constantly diminishes toward the north. Of the formation in the western part of the province but little is known, as west of London, where it consists of 500 feet of red shale, it has not been reached in the borings thus far put down.

Hudson River.—The Hudson River, which is next met with, plays a very unimportant part in the geology of gas and oil in Ontario, and consists, in that part of the province under consideration, of a series of shales and limestones immediately underlying the red and green shales of the Medina. Unfortunately the great area of its supposed exposure north of Toronto is overlaid with drift, but where the exposures are to be seen they consist, as in the township of Toronto, Peel county, "of a series of bluish-gray argillaceous shales enclosing bands of calcareous sandstone sometimes approaching to a limestone and of variable thickness."* These sandstone bands are slaty in places, though at times having a solid thickness of a foot. The formation has been reached in a considerable number of wells—among others, those at Saint Catharines, Thorold, number 14 of the Provincial company, in Bertie, all in the Niagara peninsula; Swansea and Mimico, near Toronto; Toronto, Hamilton, Brantford and London, where it was penetrated for 150 feet and found to consist of limestone and shale. In the wells at Swansea and Mimico there were found 440 and 493 feet respectively of bluish-gray shale. This does not of necessity represent the total thickness of the formation at these points, as boring began upon it immediately beneath the surface deposits. In the Thorold well, where the formation was met with at depth, it was found to consist of 700 feet of blue shale, and at Saint Catharines it had a similar character and thickness. It is quite probable that in the various borings limestone was found, though on account of its shaly character it was termed shale by the drillers.

Utica.—The Utica formation, upon which the Hudson river rests, is found, wherever met with in drillings, to consist of a series of dark-brown bituminous shales, becoming in places bluish toward their base, and having a thickness of from 200 to 400 feet. Of its exact thickness in any well it is very difficult to speak, on account of the similarity between its upper members and the lower strata of the Hudson river.

Trenton and Black River.—Beneath the Utica shales there is met with a thick series of bluish limestones, which constitute the Trenton formation, including also the Black River. This series, which is regarded as the Mecca of all Ohio drillers, has proved itself, in Ontario, to be com-

* Geology of Canada, 1863, p. 212.

paratively barren of gas or oil. Of its productive properties, however, more will be said later. In eastern Ontario it covers a large area, but west of Toronto and Collingwood the series is overlaid by the Utica and newer formations, with the exception of a small area in the vicinity of Collingwood, where it is seen to consist of bluish limestone, having a slight dip to the southwest. In the few wells wherein it has been reached the character of the rocks is apparently unchanged, though its thickness varies considerably. For instance, at Whitby, east of Toronto, it has a thickness of 600 feet; at Toronto, 585 feet; Swansea, 602 feet; Collingwood, 553 feet, and Saint Catharines, 667 feet, in all of which places the formation was entirely traversed, the drillings, with the exception of the well at Saint Catharines, ceasing on the striking of the Archean rocks immediately beneath. In the case of the boring at Saint Catharines the drill penetrated 27 feet of white quartzose sandstone, which may be Paleozoic or belong to the arkose beds.

Geologic Horizons in Ontario yielding Gas and Oil.

OIL WELLS IN THE CORNIFEROUS LIMESTONE.

Age and Depth.—Of the occurrence of petroleum in Ontario but little can be said. In Lambton county, where it has been produced for 30 years, it is found in the Corniferous limestone at a depth of about 475 feet, the record of a well bored near the Imperial refinery, Petrolea, being as follows:

Formation.	*Strata.*	*Thickness in feet.*
	Surface deposits	104
Hamilton	Limestone	40
	Shale	130
	Limestone	15
	Shale	43
	Limestone	68
Corniferous	Limestone, soft	40
	Limestone, gray, oil rock	25
	Depth	465

Annual Output of Oil.—Some 3,000 wells are now producing and afford about 800,000 barrels per annum, making the average daily production about two-thirds of a barrel per well. The oil is dark-colored and of from 31° to 35° Baumé in gravity; nor is it an oil that can be easily refined, on account of the considerable proportion of sulphur it contains in a form as yet undetermined.

Chemical Composition of the Oil.—According to returns received from the refineries for the year 1889 it has a commercial content of—

Benzine and naphtha	1.6	per cent.
Illuminating oil	38.7	"
Paraffine, gas and other oils and wax	25.3	"
Waste (coke, tar and heavy residuum)	34.4	"
	100.0	"

The Corniferous petroliferous over a wide Area.—While the Corniferous affords commercial quantities of oil only in Lambton county, explorations have proved it to be petroliferous over a wide extent of country, including the northern part of Kent, the eastern part of Middlesex, and southern part of Oxford. In the county of Essex oil has been found at two points, presumably in the Niagara or upper strata of the Clinton. At Comber, in this county, small quantities of heavy black oil were found in a hard limestone at 1,270 feet, and again at Walker's well number 2, on lot 8, concession 6, Colchester township, oil similar in appearance and gravity was found at 1,000 feet in a brownish limestone. This well is said to have pumped five barrels per day.

THE MEDINA AS AN OIL-PRODUCER.

The only other formation wherein oil has been struck is the Medina, in which, in Humberstone township, Welland county, it has been noted in two wells. These are on lots 11 and 12, concession 3, and are said to have flowed four and two barrels each per day respectively. The oil occurs in the second white sandstone bed, about 100 feet beneath the summit of the formation. The oil is of light claret color, of about 45° Baumé gravity, and is apparently free from sulphur. Further work in search of this oil has not yet been undertaken.

GAS-BEARING HORIZONS: CLINTON, MEDINA AND OTHERS.

Localities indicated.—Gas is found in large quantities at two horizons only, viz, one, which is still doubtful though in the neighborhood of the Clinton, in Essex county; and in the Medina, in Welland. In the former county, in the vicinity of Ruthven, Gosfield township, there have been sunk several wells, in three of which were found large quantities of gas, in each case emanating from a gray vesicular dolomite at a depth of about 1,000 feet.

Depth at which Gas is found.—In Welland county, wherein the gas field covers a much greater area than that of Essex, the gas is found almost entirely in the Medina sandstone, about 100 feet below the summit of the formation and at a depth of about 830 feet. The record of number 1

well, drilled on lot 35, concession 3, Bertie township, by the Provincial Natural Gas and Fuel company, is a follows:

Formation.	*Strata.*	*Thickness in feet.*
	Surface deposits	2
Corniferous	Dark-gray limestone	23
Onondaga	Gray and drab dolomites, black shales and gypsum	390
Guelph and Niagara	Gray dolomite	240
Niagara	Black shale	50
Clinton	White crystalline dolomite, gray toward bottom	30
Medina	Red sandstone	55
	Red shale	10
	Blue shale	5
	White sandstone	5
	Blue shale	20
	White sandstone ("gas-rock")	16
	Total	846

Records of twenty-eight Wells.—In the above well 2,000,000 cubic feet of gas per day were struck at a depth of 836 feet, or six feet in the second white sandstone bed. This company have drilled some thirty wells, the records of which do not differ materially from that given above, though capacity varies greatly, as may be seen from the following table:

Number of the well.	*Cubic feet per day.*	*Number of the well.*	*Cubic feet per day.*
1	2,050,000	15	50,000
2	375,000	16	12,500,000
3	600,000	17	2,500,000
4	2,200,000	18	2,000,000
5	8,500,000	19	1,500,000
6	70,000	20	300,000
7	3,000,000	21	None.
8	47,000	22	2,600,000
9	3,500,000	23	30,000
10	4,500,000	25	500,000
11	300,000	26	2,750,000
12	5,500,000	27	None.
13	300,000	28	Limited.
14	5,000		

Gas-bearing Bed of the Medina.—In all of these wells, with the exception of number 22, the entire flow was obtained from the second white sandstone bed of the Medina; nor are these the only wells producing large quantities of gas from that horizon, as shown below.

Daily Capacity of some of the Wells.—The largest gas well is that known as Coste number 1, drilled by the Ontario Natural Gas company on lot 7, concession 1, of Gosfield, and carried to a depth of 1,021 feet, wherein

at 1,017 feet a flow of gas equal to 10,000,000 cubic feet per day was found. Another was drilled by the Citizens' Gas, Oil and Piping company of Kingsville on the road allowance about 55 yards west of the above-mentioned well, and afforded 7,000,000 feet per day, from a rock similar in character and depth to that in Coste number 1. On lot 7, concession 1, of Gosfield, the Citizens' company again drilled and found gas to the extent of 2,500,000 cubic feet per day, and I understand that the Ontario company have been quite successful in a boring made southeast of their Coste number 1, having obtained there a heavy flow, estimated at 7,000,000 feet per day. All efforts to find gas north and northwest of this group of wells have been futile, the beds being found to be flooded with salt water.

Other Localities.—Among other lesser producers may be mentioned Carrolls, in Humberstone township, which afforded 1,000,000 cubic feet per day. At Cayuga, in Haldimand county, west of Welland, a considerable flow was found in the Medina as well as at Dunnville, about midway between Port Colborne and Cayuga. In wells bored to or through the Medina north and northwest of Welland, and the wells mentioned above, the formation has been found to be practically barren of gas, the only boring wherein it was noted being at Beeton, where in a soft sandstone just beneath the surface deposits a small quantity occurred.

The Clinton as a Gas-producer.—The Clinton in a small number of wells has afforded large quantities of gas, the most marked instances being those in Welland county, known as Near's, Reebe's and Hopkins' number 2, each of which produced 400,000 cubic feet per day, and the Mutual company's well, which produced 1,500,000 cubic feet. These wells are all in that district wherein the Medina is so productive, a fact that rather tends to suggest that the gas is adventitious. Outside of this county the Clinton has not as yet produced a single cubic foot of gas. Exception must, of course, be taken to this statement if it be proved that the productive horizon in Essex county is in that formation.

The Niagara as a Gas-producer.—In Welland county the Niagara also is a large producer of gas, well number 22 of the Provincial company affording 1,850,000 cubic feet per day from the limestones of the upper part of the formation, while in a well sunk a few miles north of this, at Niagara Falls South, a flow of 50,000 cubic feet was obtained in the shales beneath the limestone.

OTHER GAS-BEARING FORMATIONS.

There now remain to be spoken of only three formations which have afforded gas, though only as yet in small quantities. They are the Onondaga, the Trenton, and a sandstone of age anterior to the latter.

The Onondaga as a Gas-producer.—The occurrence of gas in the Onondaga, even in the small quantities noted, is unique. At Blyth, Huron county, and in the midst of a considerable number of wells bored in the salt region, a well was drilled which afforded, according to the driller, the following record:

Surface deposits	104 feet.
Limestone	300 "
(?)	346 "
"Black shale"	100 "
"Hard rock"	170 "
Shale	105 "
Rock-salt	90 "
Total	1,215 "

In the black shales considerable quantities of gas were obtained, not, however, sufficient to be of commercial value.

The Trenton as a Gas-producer.—The Trenton formation has not as yet afforded any considerable quantities of gas, though pierced at many points, the most westerly being Stratford, where it was found at 2,360 feet and penetrated for 24 feet, where a heavy flow of salt water caused the abandonment of the work. Coming eastward, the point where it was next struck was on lot 16, concession 15, Brantford township, Brant county, where it was reached at a depth of 1,950 feet and a small quantity only of gas obtained at its summit. At Dundas, near Hamilton, in Wentworth county, it was struck at 1,430 feet and found to be barren. Again, at Thorold, Welland county, about 40 miles east of Hamilton, the Trenton was struck at 1,905 feet and penetrated for 525 feet, where a very small flow of gas was noted. About 8 miles north of this, at Saint Catharines, it was again reached, being struck at 1,506 feet and found to be barren, although the entire formation was traversed. Again east of Thorold and on lot 6, concession 15, of Bertie township, it was struck at 2,525 feet in well number 14 of the Provincial company, wherein it was traversed for 195 feet without affording gas. The foregoing three wells are the only ones in which the Trenton was reached south of Lake Ontario. On the northern side, however, it has been met with in all wells drilled close to the lake shore. In Toronto several wells were sunk, operations commencing upon the Hudson River formation and the drilling continued deep into or through the Trenton without finding gas; but at Mimico, about 8 miles west, three wells have afforded small quantities, the greatest flow being about 50,000 cubic feet per day. In and around Collingwood several wells, beginning in the upper beds of the formation and continued to its base, afforded small flows, the greatest being about 6,000 cubic feet per day.

It will thus be seen that in Ontario the Trenton as a large producer has proved so far anything but successful. Even at Dundas, on the crown of the Dundas anticlinal, no gas was found. There, however, remains in the western and southwestern portion of the province a large area as yet untouched, wherein it may afford large quantities and prove of as great value as it has further southward, in Ohio.

The following table exhibits the position of the Trenton in southwestern Ontario in regard to tide level.

Locality of well.	Elevation of well above tide.	Elevation of summit of Trenton.	Thickness of Trenton.	Elevation of base of Trenton.	Gas in Trenton—cubic feet per day.
	Feet.	*Feet.*	*Feet.*	*Feet.*	
Toronto, Swansea ...	347	— 296	602	— 898	None.
Mimico	280	— 443	....	Not reached.	About 5,000
Collingwood, City...	592	Begun on	Trenton..	+ 39	" 5,000
" Delphi.	600	+ 552	....	Not reached.	" 6,000
Dundas	About 300	— 1,130	....	....do	None.
Saint Catharines....	297	— 1,209	667	— 1,876	None.
Thorold ..	517	— 1,388	....	Not reached.	Very small.
Provincial company, number 14........	About 620	— 1,905	....	....do	None.
Brantford	672	— 1,278	....	....do	Very small.
Stratford	1,185	— 1,175	....	....do	None.

Unfortunately no analyses or close examinations have as yet been made of the Trenton limestone in that part of the province under consideration, the only analyses available being those of specimens from quarries considerably to the east of the portion where it is under cover.

An unusual Occurrence of Gas.—A rather peculiar occurrence of gas is that found in the well near Saint Catharines. In this boring a yellow quartzose sandstone beneath the Trenton limestone was penetrated for seventy-seven feet and afforded a small quantity of gas, insufficient for commercial purposes.

Forthcoming Publication on the Subject.

In closing, I should like to draw attention to the fact that a detailed description of wells bored in Ontario, accompanied by maps and sections, is now in press and will shortly be issued by the Canadian Geological Survey. In this will be found a more or less complete narrative of boring operations up to the close of the calendar year 1890.

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NOTES ON THE OCCURRENCE OF PETROLEUM IN GASPÉ, QUEBEC

BY H. P. H. BRUMELL

(*Read before the Society December 30, 1892*)

CONTENTS

EARLIER HISTORY.

The Locality indicated.—Operations in search of petroleum have been carried on in a desultory manner for about 30 years in the vicinity of Gaspé basin, Gaspé county, Quebec, without as yet any economic result. The presence of oil at depth has, however, been proved through the efforts of "The Petroleum Trust," an English company, which has been operating on the southwest side of Gaspé bay, in the neighborhood of and to the south of Gaspé basin.

The Oil-bearing Formation described.—In the eastern part of the Gaspé peninsula there is a great thickness of sandstones resting conformably upon almost as great a thickness of limestones, the whole being of lower Devonian and possibly partly Upper Silurian age. According to Dr R. W. Ells,* these sandstones have a thickness of about 3,000 feet, while the

* Report of Progress, Geol. Survey of Canada, 1880–82, p. 5 D D.

underlying limestone is estimated at about 2,000 feet. These rocks are largely developed in the vicinity of Gaspé bay, where they form a series of almost parallel anticlinals, on or near the axes of which the greater part of the exploratory work has been done.

Dr R. W. Ells, in the report cited above, speaks of these anticlinals as follows:

"The rocks of the series have a considerable development on the several rivers that flow into Gaspé bay, where they lie in shallow basins, bounded by the anticlinals, which bring into view the strata of the lower or Gaspé limestone series. These basins are at least four in number, the dividing anticlinals being known as the Haldimand, the Tar Point, the Point Saint Peter, and the Percé, the most southerly yet recognized. On the south side they rest upon rocks of the Silurian system. The whole formation may therefore be said to occupy a geosynclinal basin, the western limit of which has not yet been traced, but which will probably be found to be continuous with the basin recognized on the Cascapedia river, and thence extending to the Metapedia."

Former Knowledge concerning the Locality.—In the "Geology of Canada," 1863, page 789, the following mention is made of the various natural oil springs of the district. This includes probably all that was known of the occurrence of oil in Gaspé up to that date:

"At the oil spring at Silver brook, a tributary of the York river, the petroleum oozes from a mass of sandstone and arenaceous shale, which dips southeastwardly at an angle of 13° and is nearly a mile to the south of the crown of the anticlinal. The oil, which here collects in pools along the brook, has a greenish color and an aromatic odor, which is less disagreeable than that of the petroleum of western Canada. From a boring which has been sunk in the sandstone to a depth of about 200 feet there is an abundant flow of water, accompanied with a little gas and very small quantities of oil. Farther westward, at about twelve miles from the mouth of the river, oil was observed on the surface of the water at the outcrop of the limestone. Petroleum is met with at Adams' oil spring, in the rear of lot B of York, nearly two miles east of south from the entrance of Gaspé basin. It is here found in small quantities floating upon the surface of the water, and near by is a layer of thickened petroleum, mixed with mold, at a depth of a foot beneath the surface of the soil. A mile to the eastward, at Sandy beach, oil is said to occur, and, again, at Haldimandtown, where it rises through the mud on the shore. These three ocalities are upon the sandstone and on the line of the northern anticlinal which passes a little to the north of the Silver Brook oil spring. Farther to the southeast, on the line of the southern anticlinal and about two miles west of Tar Point, which takes its name from the petroleum found there, another oil spring is said to be found, three-quarters of a mile south of Seal cove. On the south side of the Douglastown lagoon, and about a mile west of the village, oil rises in small quantities from the mud on the beach. A well has here been bored to a depth of 125 feet in the sandstone, which dips to the southwest at an angle of 10°, but traces only of oil have been obtained. Farther to the westward oil is said to occur on the second fork of the Douglastown river. Traces of it have also been observed in a brook

near Saint George's cove, on the northeast side of Gaspé bay. In none of these localities do the springs yield any large quantities of oil, nor have the borings, which have been made in two places, been as yet successful. The above indications are, however, interesting, inasmuch as they show the existence of petroleum over a considerable area in this region, some part of which may perhaps furnish available quantities of this material."

Recent Exploitation.

History of later Operations not fully known.—Regarding later operations but little is known, as owing to the distance from our usual fields of work and the disinclination of operators to impart information it has been found impossible to closely follow actual operations. However, this much is known, that oil has been found at some depth, though in small quantities.

Notes on past and present Investigations.—The following notes are gleaned from a report on mines and minerals of the province of Quebec recently prepared by J. Obalski, M E, supplemented by information obtained by the writer:

At Sandy Beach, on lot B, York township, two wells were sunk about 20 years ago, one of which is said to have afforded oil, and about a mile above Douglastown, on the southern side of the Saint John river, a well was sunk 125 feet without successful result. At Silver Brook two wells were bored to a depth of 800 and 900 feet respectively, both showing the presence of petroleum, and on the southern side of the York river, near Silver Brook, two borings were made by the Gaspé Oil company to a depth of 700 and 800 feet, in neither of which was oil struck. Subsequent to these a well was sunk at Sandy Brook to a depth of 700 feet, in which oil was found, though in small quantity. The oil, a specimen of which was collected in 1882 by the writer, was brought to the surface of a small pool by the water, which flowed in considerable quantity from the boring, and was a heavy black oil of about 25° Baumé gravity.

In 1888 the International Oil company of Saint Paul, Minnesota, sunk a shallow well, which was in 1889 deepened to 450 feet without finding oil. The lands and plant owned by this company were in the same year taken over by "The Petroleum Trust," which has since sunk five wells in the district. In one of these, bored at Seal cove, a short distance south of the crown of the Tar Point anticlinal, they have met with a small quantity of high-grade oil. According to one of the drillers, the boring reached a depth of 3,000 feet, of which the upper 2,150 consisted of yellow and white sandstone, followed by 850 feet of bluish shaly limestone, in which, at a depth of about 2,600 feet from the

surface, the oil was found. The oil, which is green in color, is of about 38° Baumé gravity, has an aromatic odor, and is bright ruby red by transmitted light.

Continuation of Investigations probable.—The company working at present expect to continue operations, the results of which, in view of the probable exhaustion in the near future of the Petrolea field in Ontario, will be watched with interest.

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THE FAUNAS OF THE SHASTA AND CHICO FORMATIONS

BY T. W. STANTON

(Read before the Society December 30, 1892)

CONTENTS

Historical Review.

Earliest Literature.—The earliest published opinion concerning the age of the beds now known as the Chico formation seems to be that of Dr J. B. Trask,* who described *Ammonites chicoensis* and *Baculites chicoensis* in 1856. On account of the modern aspect of the fossils associated with those species he referred the strata containing them to the upper Eocene. Shortly afterward Professor J. S. Newberry † discussed the same beds,

* Proc. Cal. Acad. Nat. Sci., vol. i, 1856, p. 85.

† Pacific R. R. Reports, vol. vi, pt. 2 [1857 ?], pp. 24, 25. The title-page bears the date 1855, but there is internal evidence that the volume was not published before 1857.

and, while admitting the presence of modern types of mollusks, considered that the cephalopods were stronger evidence of their Cretaceous age. He also stated that he had obtained a collection of fossils from Nanaimo, Vancouver island, that proved the Cretaceous age of the coal beds at that place. These fossils were placed in the hands of Professor F. B. Meek,* who soon afterward described them. Although at that time he thought that the entire collection came from Nanaimo, he believed that two distinct horizons were represented. Many years afterward, when republishing the descriptions with figures,† he stated that only those species which he believed to be the older came from Nanaimo, while the others were from Comox, northwest of Nanaimo, and from Sucia island. Those from the last two localities were thought to indicate about the horizon of the Fort Pierre shales, or number 4 of Meek and Hayden's upper Missouri section.‡

In 1858 Dr B. F. Shumard § described three species of Cretaceous fossils from Nanaimo, and in 1861 Dr James Hector || published an account of the Nanaimo coal field, giving the evidence of its Cretaceous age.

Views of W. M. Gabb.—Up to this time both the geologic and the paleontologic work had been mainly preliminary, the latter based on very small collections brought in by explorers; and it was not until 1864, when the first volume of the Paleontology of California was published, that any serious attempt was made to classify the Cretaceous formations of the Pacific coast or to present their paleontology in a systematic manner. In that volume Mr W. M. Gabb described about 260 species of fossils which he referred to the Cretaceous. In the introduction some general statements concerning the classification and correlation of the California Cretaceous were given by Professor J. D. Whitney,¶ the state geologist, on the authority of Mr Gabb. All the Cretaceous beds on the Pacific coast were assigned to two divisions (*A* and *B*), which were together supposed to represent the Upper Chalk or White Chalk of Europe and the Fort Pierre and Fox Hills groups of the upper Missouri, although the Cretaceous of the latter region seemed to have no species in common with the California strata.

The Tejon Controversy.—The publication of this volume precipitated a discussion between Messrs Gabb, Conrad and others as to the age of

* Trans. Albany Institute, vol. iv, 1858–'64, pp. 36–49.

† Bull. U. S. Geol. Surv. Terr., vol. ii, 1876, pp. 351–374.

‡ The same opinion is expressed in Professor Meek's last work, U. S. Geol. Surv. Terr., vol. ix, Invert. Paleontology, p. xxv.

§ Trans. St. Louis Acad. Sci., vol. i, 1858, pp. 123–125.

|| Quart. Jour. Geol. Soc. Lond., vol. xvii, 1861, pp. 428–436.

¶ Paleontology of Cal., vol. i, 1864, p. xix.

division "*B*," now known as the Tejon formation, Mr Conrad asserting that it is Eocene and Mr Gabb as strenuously maintaining its Cretaceous age.* On the one hand, the unquestionable fact that a number of the fossils are identical or closely related with species that elsewhere characterize the Eocene was regarded as proof of its Tertiary age; while on the other hand, the presence of an ammonite (*Ammonites jugalis*) and the apparently close faunal and stratigraphic connection with the Cretaceous beds beneath were believed to prove its Cretaceous age. According to Mr Gabb's † statement in one of his controversial articles, 23 species of the 107 in division *B* are found in the underlying beds. When his list of common species is critically examined, however, it is seen that, with the exception of the *Ammonites* and perhaps two or three others, they all belong to genera that have lived from the Cretaceous or earlier to the present time without undergoing much change. Professor Angelo Heilprin ‡ has given a careful review of all the published evidence bearing on this question, and in preparing it he has studied a large part of Mr Gabb's original collections of California fossils. His article is a strong argument for the Eocene age of the Tejon and incidentally it throws considerable doubt on the accuracy of Mr Gabb's statements concerning the species that occur in both the Chico and the Tejon.

Professor Jules Marcou§ and Dr C. A. White || have also referred the Tejon, or division *B*, to the Eocene, and this view is now generally accepted. While admitting its Tertiary age, both Dr White ¶ and Dr G. F. Becker,** after studying the subject in the field, have stated their belief that in southern California the Tejon, is only the upper part of an unbroken series, the Chico-Tejon, in which the sedimentation as well as the life was continuous from the Cretaceous into the Tertiary.

In the second volume of the Paleontology of California, published in 1869, Professor Whitney †† again summarized Mr Gabb's latest views on the classification of the Cretaceous. Division *B* is named the Tejon and considered to be the probable equivalent of the Maestricht beds. Division *A* is separated into three groups: the Martinez group, which is doubtfully separated from the one next below; the Chico group, which

*Conrad's articles are in Am. Jour. Conch., vol. i, 1865, pp. 362–365; vol. ii, 1866, pp. 97–100, and Am. Jour. Sci., vol. xliv, 1867, pp. 376–377. Gabb's replies may be found in Am. Jour. Conch., vol. ii, pp. 87–92; Am. Jour. Sci., vol. xliv, pp. 226–229, and Proc. Cal. Acad. Nat. Sci., vol. iii, 1867, pp. 301–306.

† Proc. Cal. Acad. Nat. Sci., vol. iii, 1867, p. 302.

‡ Proc. Acad. Nat. Sci. Phila., 1882, pp. 195–214; Contributions to Tertiary Geol. and Paleont. of the United States, 1884, pp. 102–117.

§ Bull. Soc. Géol. de France, tome xi, 1883, pp. 417–435.

|| Bull. 15, U. S. Geol. Survey, 1885, pp. 11–17; Bull. 51, 1889, pp. 11–14; Bull. 82, 1891, p. 193.

¶ See references just given.

** Bull. 19, U. S. Geol. Surv., 1885.

†† Pages xiii and xiv.

is correlated with the Upper Chalk or Lower Chalk and, it is thought, may prove to be the equivalent of both, is said to include all the known Cretaceous of Oregon and of the extreme northern part of California and the coal-bearing beds of Vancouver island; and the Shasta group, provisionally formed to include a series of beds of different ages below the Chico. According to Whitney "it contains fossils, seemingly representing ages from the Gault to the Necomian, inclusive. . . . Few or none of its fossils are known to extend upward into the Chico group."

Work of the Canadian Geological Survey.—In 1871 the geological survey of Canada began the work in British Columbia which has contributed greatly to our knowledge of the Mesozoic formations of the Pacific coast. It is beyond the scope of this paper to consider the detailed geologic description of the Cretaceous on Vancouver and Queen Charlotte islands and the mainland of British Columbia, as given by Mr James Richardson* and Dr George M. Dawson.†

These reports have shown that the Cretaceous attains thicknesses of over 5,000 feet on Vancouver island and of about 13,000 feet on Queen Charlotte islands. The invertebrate fossils from both these areas have been described and fully discussed by Mr J. F. Whiteaves.‡ The most recently published conclusions of this author are that the larger part (divisions *C*, *D*, and *E*) of the Queen Charlotte islands section is the equivalent of the Shasta formation, and that the same horizon is represented in the northern part of Vancouver island and at several localities on the mainland of British Columbia; that the beds of the Nanaimo and Comox coal fields on the eastern coast of Vancouver island are more recent and referable to the Chico formation, and that none of these beds are older than the Gault. Previously Mr Whiteaves had expressed the opinion that the Shasta formation and its equivalents in British Columbia should be separated into two formations, referring the older beds, which are especially characterized by an abundance of *Aucella*, to the Necomian and the upper portion to the Gault; but additional collections showed such a blending of the faunas that they could not be separated and this view was abandoned.

* Report on the coal fields of the east coast of Vancouver Island: Geol. Surv. Canada, Rept. of Prog. 1871–'72, pp. 73–100; Rept. on the coal fields of Vancouver and Queen Charlotte Islands: Ibid., 1872–'73, pp. 32–65.

† For example—Report on the Queen Charlotte Islands: Ibid., 1878–'79, pp. 1–101 B; On a Geological Examination of the northern Part of Vancouver Island: Ann. Rept. Geol. Survey Canada, 1886, pp. 1–107 B; On the earlier Cretaceous Rocks of the northwestern Portion of the Dominion of Canada: Am. Jour. Sci., vol. xxxviii, 1889, pp. 120–127.

‡ Geol. Survey Can.: Mesozoic Fossils, vol. i, pt. 1, Invertebrates from Queen Charlotte Islands, 1876; pt. 2, Fossils of the Cretaceous Rocks of Vancouver, 1879; pt. 3, Fossils of the coal-bearing deposits of Queen Charlotte Islands, 1884. See also Trans. Roy. Soc. Canada, vol. i, 1882, sec. iv, pp. 81–86, and Cont. to Canadian Paleont., vol. i, pt. 2, 1889.

White's Classification of the California Cretaceous.—Dr C. A. White, whose work on the Cretaceous of California has already been referred to, also recognized two divisions in the Shasta, to which he gave the local names, Knoxville and Horsetown beds, although he believed them to be closely related; and several species of the Horsetown fauna were afterward found associated in the same strata with *Aucella*, the characteristic fossil of the Knoxville beds, near Riddles, Oregon.* It may therefore be regarded as established that the Knoxville beds should not be considered distinct from the remainder of the Shasta formation, although they may usually be recognized by the great abundance of *Aucella*, a fossil that seems not to range into the upper part of the series.

The great apparent difference in the faunas of the Shasta and the Chico formations at the localities studied by him led Dr White to believe that there is a break between these two formations, representing a great time-hiatus,† although they are apparently conformable. The list of species assigned to each formation by Mr Gabb also seemed to justify this belief, but the sequel will show that the stratigraphic position and the vertical range of many of the species were very imperfectly known until quite recently.

Relation of Shasta and Chico Faunas.

Identity of Faunas indicated.—Various members of the United States Geological Survey working in California and Oregon during the last few years have from time to time made small collections of Cretaceous fossils that have been submitted to Dr White for examination. The largest of these collections was received from Mr J. S. Diller in 1889, and was assigned to me for study and identification, under the direction and supervision of Dr White. The collection embraced small lots of fossils from about seventy-five different localities in northern California and southern Oregon, the most of which are in the valley of Sacramento river.‡ There were usually only a few species of fossils from each locality, as they were collected by the geologists in connection with other field-work and without any attempt at making exhaustive collections. The fossils were identified and those from each locality were, so far as practicable, assigned to the Shasta or to the Chico-Tejon, in accordance with the distribution of species in those formations given by Mr Gabb. But some of the localities seemed to show a mixture of Shasta and Chico species, and when

*See G. F. Becker, Notes on the early Cretaceous of California and Oregon: Bull. Geol. Soc. Am., vol. 2, 1891, pp. 204–205.

†See Bull. U. S. Geol. Survey, numbers 15, 22, 51 and 82.

‡For description of the geology of this region and further discussion of the paleontology see Mr Diller's paper, this volume, pp. 205–224.

Mr Diller plotted all the localities on the map those that were assigned to different horizons were seen to be inexplicably mixed. Mr Diller at that time suggested that the two faunas were more closely related than had hitherto been supposed, but the evidence did not then seem to be conclusive.

Local Lists of both Faunas from northern California.—During the past field season Mr Diller had considerable collections made at Horsetown,* Shasta county, California, and at Texas springs, less than two miles east of Horsetown. These fossils, which have recently been studied, gave unquestionable proof of the blending of the Shasta and Chico faunas. Mr Diller says that the beds from which the fossils were collected at these two localities are of no considerable thickness. Besides the nature of the matrix, the state of preservation of the fossils and the manner in which the species are commingled on hand specimens, all indicate that the entire collection came from the same horizon. I have therefore listed the fossils from both localities together, as follows:

**Ammonites hoffmanni*, Gabb.
**Ammonites breweri*, "
**Diptychoceras lævis*, "
Ancyloceras (?) lineatus, "
**Belemnites impressus*, "
Liocium punctatum, "
**Lunatia avellana*, "
Gyrodes.
Fusus aratus, Gabb.
**Anisomyon meekii*, Gabb (?)
Scalaria albensis (?), D'Orb., Whiteaves.
Actæonina californica, Gabb.
Cinulia.
†Ringicula varia, Gabb.
**Ringinella polita*, "
†Panopæa concentrica, "
†Cucullæa truncata, "
†Nemodon vancouverensis, Meek.
†Trigonia æquicostata, Gabb.
†Trigonia leana, "
Trigonia.
†Pecten operculiformis, Gabb.
†Thetis annulata (Gabb) = *Cardium (Lævicardium) annulatum.*
†Corbula traskii, Gabb.
†Mytilus quadratus, Gabb (?)
Mytilus lanceolatus, Sowerby.
†Leda translucida, Gabb.
**Pleuromya lævigata*, Whiteaves.
†Tellina hoffmanniana, Gabb.
†Tellina mathewsonii, "
†Mactra ashburneri, "
†Chione varians, "
†Meekia radiata, "
†Meekia navis, "
†Meekia sella, "
Rhynchonella.

* Most of the localities mentioned are shown on the sketch map prepared by Mr J. S. Diller, forming plate 4, page 205, of this volume.

*† The species belonging to Mr Gabb's Shasta fauna are marked with an asterisk (*), those belonging to the Chico with an obelisk (†). The others have not been positively assigned to either horizon.

Mr Gabb's nomenclature is used, in most cases without revision, throughout this paper.

Of the 36 species in this list, the Paleontology of California gives 8 as coming from the Shasta and 18 from the Chico, while 2 of the others are doubtfully referred to the former and 2 to the latter. At least 12 of these species are also represented by identical or very closely related species in the Queen Charlotte islands (lower shales), and 7 are similarly represented in the equivalent of the Chico on Vancouver island.

It will be remembered that Horsetown is a typical and well known Shasta locality, and that the types of two of Mr Gabb's species were obtained there.

Many of Mr Diller's localities for fossils are on Cottonwood creek and its branches, a few miles southwest of Horsetown. It will be instructive to group together some of these places and consider the fossils that were obtained from them. On Hulen creek, and near its mouth on Cottonwood creek, the following were collected:

Ammonites batesi, Trask.	*Trigonia evansana*, Meek.
Ammonites hoffmanni, Gabb.	*Trigonia tryoniana*, Gabb.
Ammonites remondi, "	*Nemodon vancouverensis*, Meek.
Turritella.	*Cucullæa truncata*, Gabb.
Cytherea.	*Pecten operculiformis*, "

This collection adds two Shasta and two Chico species to the Horsetown and Texas springs list.

At and about Ono, California, mostly within a mile of the village, the following species were obtained:

Ammonites batesi, Trask.	*Martesia clausa*, Gabb.
Ammonites breweri, Gabb.	*Turnus plenus*, "
Ammonites hoffmanni, "	*Pleuromya lævigata*, Whiteaves.
Ammonites remondi, "	*Trigonia leana*, Gabb.
Ammonites (*Phylloceras*) *ramosus*, Meek.	*Trigonia æquicostata*, "
Ancyloceras remondi, Gabb.	*Trigonia evansana*, Meek.
Belemnites impressus, "	*Nemodon vancouverensis*, "
Cinulia mathewsoni, " (?)	*Plicatula variata*, Gabb.
Lunatia avellana, "	*Pecten operculiformis*, "
Potamides diadema, "	*Avicula mucronata*, Whiteaves.
Ringinella polita, "	*Pinna.*
Anchura.	*Ostrea.*
Nerinæa maudensis, Whiteaves.	*Eriphyla.*

Most of the species in this list not contained in the preceding ones were originally described as from the Shasta.

Localities at Gas Point post office and on Roaring river, not far distant, yielded the following:

Ammonites chicoensis, Trask.
Turritella seriatim-granulata, Gabb, NOT Roemer.
Nucula truncata, Gabb.

On the Cold fork of Cottonwood creek the following collection was obtained:

Baculites chicoensis, Trask.		*Cucullæa truncata*, Gabb.		
Belemnites impressus, Gabb.		*Pecten traskii*,	"	(?)
Neptunea hoffmanni,	"	*Ostrea*.		
Nucula truncata,	"	*Terebratella obesa*,	"	

Two of these species are common to Horsetown and Texas springs.

Going a few miles farther southward, the first important localities are on Elder creek, on the line of one of Mr Diller's measured sections. Near Lowry's and at other places farther westward specimens of *Aucella piochii*, Gabb, were obtained, while a higher horizon about two miles east of Lowry's yielded the following species:

Gyrodes excavata (Michelin), Whiteaves.		*Venus lenticularis*,	Gabb.	
		Tellina parilis,	"	
Lunatia.		*Tellina ashburneri*,	"	
Anchura californica,	Gabb.	*Cucullæa truncata*,	"	
Dentalium stramineum,	"	*Astarte conradiana*,	"	(?)
Thetis annulata,	"	*Pecten operculiformis*,	"	
Chione varians,	"	*Avicula*.		

This lot shows a greater difference than any of the others, although it contains at least four species enumerated from other localities above given.

Sufficient evidence has therefore been presented to show that all the species from the several localities mentioned very probably belong to one fauna.

Near Redding, on Sacramento river, a large number of species were collected, many of which were not obtained at any of the above localities, but the presence there of such forms as *Cucullæa truncata*, *Trigonia evansana*, *Pecten operculiformis*, *Corbula traskii*, etc, make it probable that the beds belong to the same continuous series, though they may represent a somewhat higher horizon.

Collections from several localities in Oregon that have always been referred to the Chico formation, such as Crooked river, Siskiyou moun-

tains, Ashland, and several places in Jackson county, indicate about the same horizon as that of the bed at Horsetown.

Original Localities of Chico Fossils.—In the second volume of the Paleontology of California there is a "Synopsis of the Cretaceous invertebrate fossils of California," giving a complete list of the species then known, with the localities at which they had been obtained. For convenience in making comparisons I have made a list of the species reported from each locality there mentioned. Leaving out of consideration the localities from which only from one to three species are reported, there are sixteen localities from which Chico fossils were obtained. An examination of the faunal lists from these places show that eleven of them may be referred without question to the Shasta-Chico fauna as represented at Horsetown and in the neighborhood of Cottonwood creek. These localities are: Benicia, Cottonwood creek, Crooked creek of the Des Chutes (Oregon), Curry's, Jacksonville (Oregon), Martinez, mount Diablo, Orestimba, Pacheco pass, Siskiyou mountains and Tuscan springs. The other five localities, viz, Chico creek, Cow creek, Folsom, Pence's and Texas Flat, yielded a greater proportion of species not contained in Mr Diller's collections from Shasta county, but there are several well marked Horsetown species reported from each of these localities; and they are all so intimately related to the other Chico localities by means of species held in common with one or more of them that they cannot be regarded as belonging to another fauna.

The Martinez group of Gabb has long since been abandoned as inseparable from the Chico; and, as Mr Diller has shown in his paper on the Cretaceous and early Tertiary deposits of this region,* the Wallala formation probably also belongs in the same series.

Faunas of Queen Charlotte and Nanaimo Formations.

Correlation of Queen Charlotte Formation with the Shasta.—The correlation of the Queen Charlotte formation (divisions *C*, *D* and *E* of Dr Dawson's section) with the Shasta has already been mentioned in speaking of Mr Whiteaves' work. The additions now made to the Horsetown fauna materially increase the number of species that occur in both the Shasta and Queen Charlotte formations. It should be stated, however, that several genera of ammonites found on Queen Charlotte islands and not yet seen in the Shasta suggest a somewhat earlier period for the bed in which they occur. It would simplify the matter if it could be proved that these ammonites came from a lower horizon. It is worthy of note

* Ante, pp. 205–224.

in this connection that the upper shales and sandstones, or division *A* of the Queen Charlotte section, contain *Inoceramus problematicus*, Schloth., a species that is characteristic of the Colorado formation in the Rocky mountain region and is not known to range higher than the Turonian in Europe.

Correlation of Nanaimo Beds with the Chico.—The correlation of the Nanaimo beds on Vancouver island with the Chico formation, taken in connection with the facts already given, implies that these beds are more closely related to the Queen Charlotte formation than has been supposed, and I think that a comparison of the faunas found in the three regions, California, Vancouver and Queen Charlotte, will give evidence of this relationship. The principal facts that seem to be opposed to this conclusion are that some of the species of *Baculites* and of *Inoceramus* found on Vancouver island are apparently closely related to species in the Montana formation of Nebraska, Colorado and elsewhere in the interior region, and that the plants found in the Nanaimo coal field are said to be of upper Cretaceous types.

With the possible exception of the species just mentioned and a few others that have little diagnostic value, it is doubtful whether any of the species of the Shasta-Chico fauna occur in the upper Cretaceous beds east of the Rocky mountains.* The ammonites nearly all belong to genera that are not found in the upper Cretaceous of the interior region, and differences almost as great might be pointed out in other classes of mollusks.

These facts may readily be explained by supposing that the faunas lived contemporaneously in different oceans separated by a long continental area, but they would also be equally well explained if it could be proved that they were not strictly contemporaneous.

The Shasta-Chico Fauna compared with the Fauna of the Blackdown Beds.

Mr Whiteaves has correlated the Queen Charlotte formation with the Gault, and as confirmatory of this reference it may be of interest to give the results of the comparison I have made with one of the English Cretaceous faunas.

In Sowerby's "Mineral Conchology" 46 species of Cretaceous fossils are described from the Blackdown beds of Devonshire, England. These beds have usually been referred to the Gault, though some authors now regard them (at least in part) as representing the lowest beds of the

*See Dr C. A. White's statement on this point in Bull. 15, U. S. Geol. Surv., pp. 27–29.

Cenomanian. Of the 46 species figured by Sowerby as coming from Blackdown, at least 23, or one-half of the entire number, are represented in the Shasta-Chico fauna by closely related species. These include such well marked forms as—

From Blackdown—	*Represented in California by—*
Astarte striata.	*Eriphyla umbonata.* (?)
Cucullæa costellata.	*Nemodon vancouverensis.*
Cucullæa fibrosa.	*Cucullæa truncata.*
Exogyra conica.	*Exogyra parasitica.*
Mytilus edentulus. *Mytilus lanceolatus.*	*Mytilus lanceolatus.* (?)
Thetis major. *Thetis minor.*	*Thetis annulata.*
Trigonia aliformis.	*Trigonia evansana.*
Trigonia dædalea. *Trigonia spectabilis.*	*Trigonia leana.*
Turritella granulata.	*Turritella seriatim-granulata.* (?)

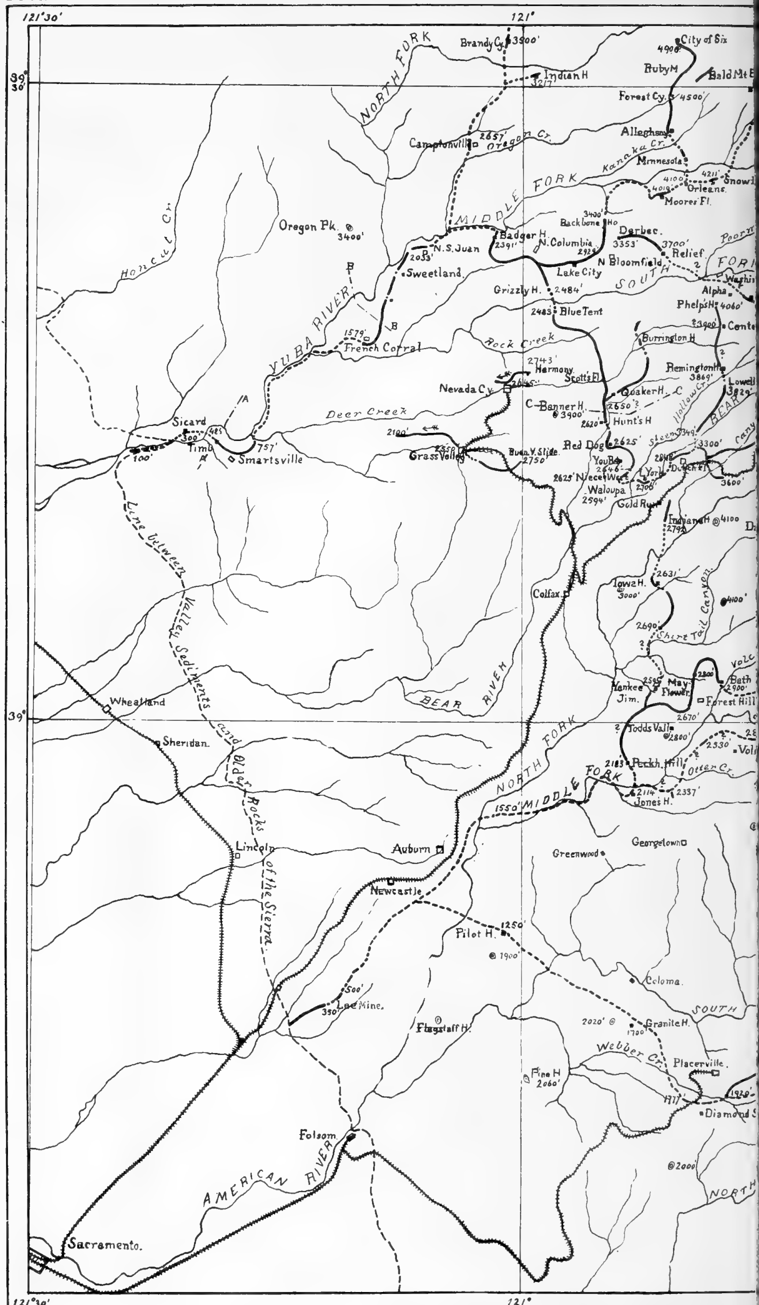
In addition to these the Blackdown beds contain a number of species belonging to the Veneridæ and Aporrhaidæ, both of which groups are well represented in the Shasta-Chico fauna. In fact, so far as can be judged by figures and descriptions, the whole fauna of the Blackdown beds, if it had been found in the western part of the United States, would be referred to the Shasta formation and about to the horizon of the Horsetown beds.

Whether the Chico beds above the fossil-bearing Horsetown horizon represent all the rest of the upper Cretaceous remains to be determined. The close relationship of their fauna to that of the underlying beds which has been compared with the Gault and Cenomanian, and its distinctness from the upper Cretaceous faunas east of the Rocky mountains representing the Turonian and Senonian of Europe seem to favor the view that a large part of the upper Cretaceous series is absent from the Pacific coast.

Conclusions.

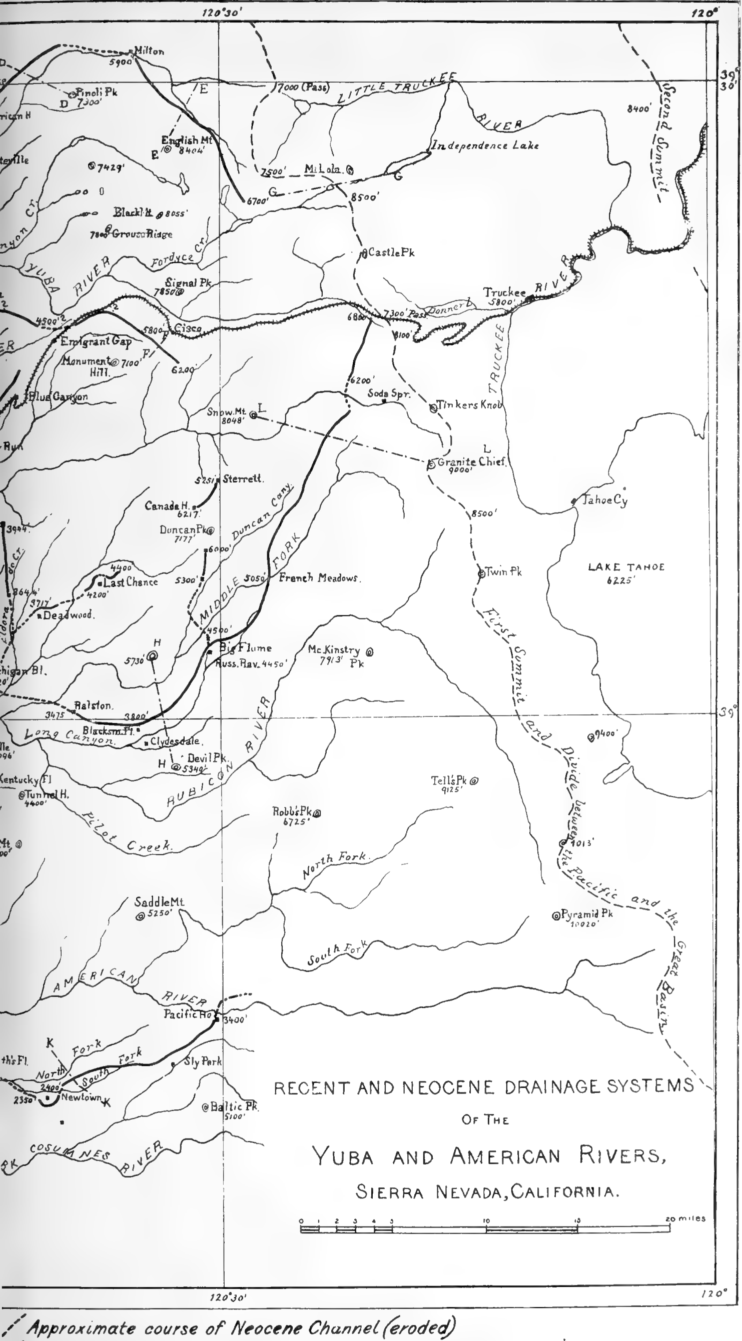
In view of all these facts, it seems to me that the exact relationship of the Chico and Tejon formations and the extent to which their faunas are connected must still be regarded as an open question that can be solved only, if at all, after exhaustive collections have been made from both formations and thoroughly studied.

The specific conclusions reached may thus be summarized: There is no faunal break any where in the entire series of strata that have been referred to the Shasta and Chico formations. Certain portions of the series are characterized by the abundance of particular species, *e. g.*, *Aucella* in the lower beds and several species and genera of ammonites in the Horsetown division; but these sub-faunas are so bound together by connecting species that they cannot be regarded as really distinct, and I have therefore adopted Mr Diller's suggestion and called the whole the Shasta-Chico fauna. The age of this fauna, or at least of the portion found in the Horsetown beds, seems to be not more recent than the Cenomanian.



©3000' Prominent Bed Rock Hills

/ Approximate course of Neocene Channel (remaining)



RECENT AND NEOCENE DRAINAGE SYSTEMS
OF THE
YUBA AND AMERICAN RIVERS,
SIERRA NEVADA, CALIFORNIA.

Approximate course of Neocene Channel (eroded)
Correct position and elevation of Neocene Channel

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TWO NEOCENE RIVERS OF CALIFORNIA

BY WALDEMAR LINDGREN

(Presented before the Society December 30, 1892)

CONTENTS

Introduction.

The investigations of the United States Geological Survey in the Gold belt of the Sierra Nevada, carried out under the direction of Dr G. F. Becker, with whose consent this paper is published, have included the geologic mapping of the country on topographic contour maps on the scale of 1 : 125,000, or about two miles to the inch. During the course of this mapping much information has been gained concerning the Neocene river channels, now largely covered by deep volcanic flows or cut away by subsequent erosion. The auriferous character of the accumulated gravels gives, as is well known, great practical importance to these channels.

A large number of the productive Neocene gravel deposits occur in the watersheds of the present Yuba and American rivers, which were included in the area assigned to the writer. It has been found that these deposits are parts of two river systems which in a general way correspond to the two modern rivers now draining the same territory.

It is the purpose of the present paper to indicate briefly the direction of the principal forks of the Neocene Yuba and American rivers, to give a more accurate idea of the Neocene topography within this district, and to call further attention to certain channels which might prove remunerative if opened by mining operations. The continuity of some of these can be asserted and their approximate position indicated. It is not proposed in this place to enter upon any elaborate discussion of the many and interesting questions connected with the accumulation of the gravels, nor is it the intention to describe in detail the often complex channel systems of any particular region.*

*The term "Neocene" has been used, consistently with the nomenclature adopted by the Survey, in preference to "Pliocene." The Neocene comprises the Miocene and Pliocene periods of the Tertiary era, between which, in the Sierra Nevada, no definite line can be drawn. It is, indeed, very probable that the first period of erosion, the gravel period and the volcanic period represent a large part of the time between the later Cretaceous and the later Tertiary, but there is no definite floral or faunal evidence to support this.

Review of Literature.

For the first accurate information as to the geologic character and occurrence of the gravel beds we are mainly indebted to the former state geological survey of California under Professor J. D. Whitney. His volume on the Auriferous gravels,* containing, besides his own extensive observations, the detailed notes of W. A. Goodyear and Professor W. H. Pettee, marks an epoch in the development of our knowledge of these Neocene deposits. The observations recorded in this book are in general accurate and trustworthy. The "review" at the end of the volume by Goodyear appears, in the light of later investigations, as very excellent indeed, and, while one may differ from some of his conclusions, it must be acknowledged that his views of the channels and of the general topography of the country over which they flowed are confirmed by more detailed and extended surveys. To these investigators belongs the credit of having established the fluviatile character and the age of the deposits, of having recognized the two important river systems corresponding to the present Yuba and American rivers, and of having begun to outline the old drainage lines. Professor Whitney concludes that the Sierra Nevada has not undergone any important changes as to the general level and the grade of its channels, and that the carving of the canyons subsequently to the gravel period was principally caused by climatic changes.

In 1886 Professor Joseph Le Conte published a paper on "A post-Tertiary elevation of the Sierra Nevada shown by the river beds,"† in which no new observations were recorded, but which gave an impetus to the investigation by the introduction of a new theory, which, however, had already been suggested by Mr G. K. Gilbert in 1883.‡ In subsequent papers Professor Le Conte has further elaborated his views,§ and in 1891 he published a paper on the "Tertiary and post-Tertiary changes of the Atlantic and Pacific coasts,"‖ in which is found a concise statement of his present opinion, which is quoted in full:

"The Sierra was formed, as we now know, by lateral crushing and strata-folding at the end of the Jurassic. But during the long ages of the Cretaceous and Tertiary this range was cut down to a very moderate height, with gentle slopes eastward

*J. D. Whitney: "The Auriferous Gravels of the Sierra Nevada of California." Memoirs of the Museum Comp. Zoöl., vol. 6, no. 1, 1880.

†Am. Jour. Sci., 3d series, vol. xxxii, 1886, p. 167.

‡Review of Professor Whitney's "Climatic Changes;" Science, vol. i, 1883, pp. 141–142, 169–173, and 192–195.

§For a more extended review of the literature regarding this subject the reader is referred to Mr H. W. Turner's "Mohawk Lake Beds." Bull. Phil. Soc. Washington, vol ix, April, 1891, pp. 385–410,

‖Bull. Geol. Soc. Am., vol. 2, pp. 323–330.

and westward from a crest which was probably situated along a line just above the Yosemite and Hetch-Hetchy valleys, for there the erosive biting into the granite axis seems to be deepest. The rivers, by long work, had finally reached their base-levels and rested. The scenery has assumed all the features of an old topography, with gently flowing curves. The continental elevation"—previously described in the same paper—"of the Pliocene did not greatly affect the river slopes of this part. At the end of the Tertiary came the great lava streams, running down the river channels and displacing the rivers; the heaving up of the Sierra crust-block on its eastern side forming the great fault cliff there and transferring the crest to the extreme eastern margin; the great increase of the western slope and the consequent rejuvenescence of the vital energy of the rivers; the consequent cutting down of these to form the present deep canyons, and the resulting wild, almost savage, scenery of these mountains."

Mr J. S. Diller, who has studied the geology of the northern end of the Sierra Nevada north of the fortieth parallel, holds similar views as to the age and elevation of the range. They were first set forth in his "Notes on the Geology of northern California,"* which, however, does not include any detailed discussion of the Tertiary river deposits on the western slope. His conclusions may be best stated by quoting from a later paper on the "Geology of the Lassen peak district:"†

"During the whole of the Cretaceous and the Tertiary the great belt of country lying east of the present Sacramento valley, embracing the region now occupied by the Sierra and a large portion of the Great Basin, was above the sea, and subjected to great degradation, which reduced it almost to its base-level of erosion. This gentle plain swept westward toward the ocean directly across the site of the present Sierra. That the north end of the Sierra country was a lowland during the Miocene, as already shown, is rendered perfectly evident by the character of its flora; and the relation of the Miocene conglomerate to the eastern escarpment north of Honey lake is such as to demonstrate that during the Miocene the Sierras were not yet in existence. Similar conditions continued through the Pliocene, for the Pliocene gravels on the western slope of the Sierras were evidently deposited while its inclination was very gentle, before the Sierra region had attained any considerable elevation, and apparently also while it was yet a part of the Great Basin platform. * * * The faulting, by means of which the Sierra Nevada range was separated from the Great Basin platform, took place, in a geologic sense, very recently. The eastern escarpment of the range, at least in its northern portion, was evidently formed after the conclusion of the volcanic activity in its immediate vicinity."

Since the above was written, Mr Diller has published a paper on the "Geology of the Taylorville region,"‡ in which he shows the Taylorville fault to be an *overthrust* instead of a *normal* fault, as he had previously supposed. This change necessarily modifies his earlier views to some extent.

* Bulletin 33, U. S. Geol. Survey, 1886.
† Eighth Ann. Rep. U. S. Geol. Survey, 1889, p. 428.
‡ Bull. Geol. Soc. Am., vol. 3, p. 369.

Dr G. F. Becker, in his paper on "The Structure of a portion of the Sierra Nevada of California,"* considers the range to have existed as such during the Tertiary. From the analysis of the extensive fissure system discovered by him he draws the conclusion that no important tilting of the Sierra has taken place at or since the post-Miocene disturbances, but that the western slope of the range has been increased by distributed faults along these systems.

For the next and very important contribution to the actual knowledge of the Neocene channels one is indebted to Mr Ross E. Browne, who gave the results of his careful and detailed survey of the Forest Hill divide in the tenth annual report of the state mineralogist of California, 1890, pages 435–465 (with maps). Mr Browne's work includes an accurate topographic mapping of the contacts of the Neocene deposits and flows with the bed-rock, surveys of all tunnels and mines, and determination of elevation of all important points. It is the first work of its kind, and stands as a model for the many similar ones which it is hoped the future will bring forth. It is gradually beginning to be recognized that detailed surveys are indispensable when works of such magnitude and cost are contemplated as the opening of important gravel channels. Both on the Forest Hill and Placerville divides large sums of money have been lost by neglecting a sufficiently extended topographic and geologic survey of the region in question.

To Mr Browne belongs the credit of having first distinctly recognized the different systems of later channels (channels of the volcanic period) as contrasted with the older pre-volcanic drainage system. In Goodyear's notes from Forest Hill and Placerville the existence of such channels is, however, plainly implied. Mr Browne also gives a diagram showing the grades of the Neocene rivers with reference to the longitudinal axis of the Sierra with the view of ascertaining whether tilting of the range can be recognized in the grades of the Neocene channels.† He thinks more data are needed, but "that the evidence, as far as it goes, is against any considerable increase in the slope of the Sierra flank—decidedly against an increase large enough to account *per se* for the two thousand feet deeper cutting of the modern river." In the same report Mr John Hobson has carefully described and mapped the Iowa Hill divide in a similar detailed way.‡

Mr Henry G. Hanks§ still appears to maintain a glacial or partly glacial origin of the gravels. I fear that in upholding this theory he is contending against very heavy odds. No evidence whatever of the ex-

* Bull. Geol. Soc. Am., vol. 2, pp. 61 and 73.
† Op. cit., p. 445.
‡ Op. cit., p. 419.
§ Mining and Scientific Press, San Francisco, April 5, 1890, and following numbers.

istence of Neocene glaciers has thus far been met with in the highest part of the range in this latitude; nor is it likely, in view of the character of the Neocene flora high up on the flank of the range, that such evidence will be found.

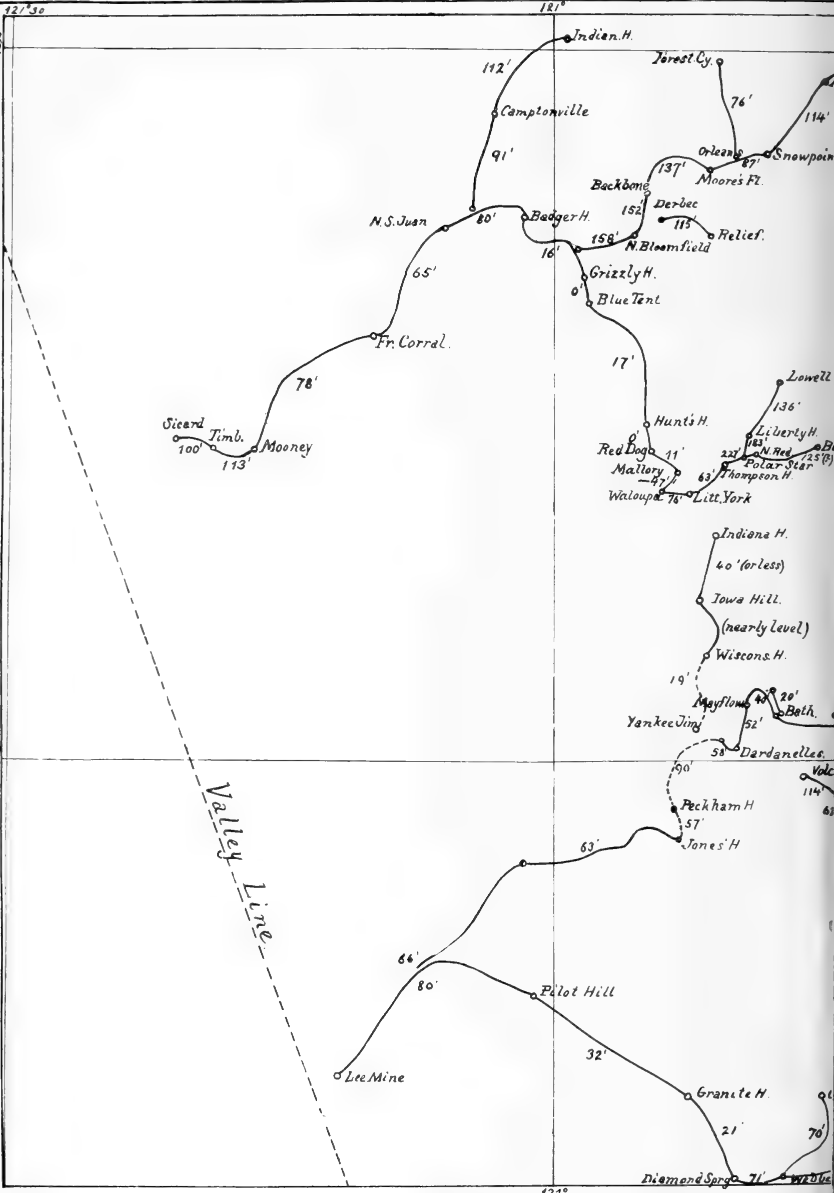
Observations on Method of Work.

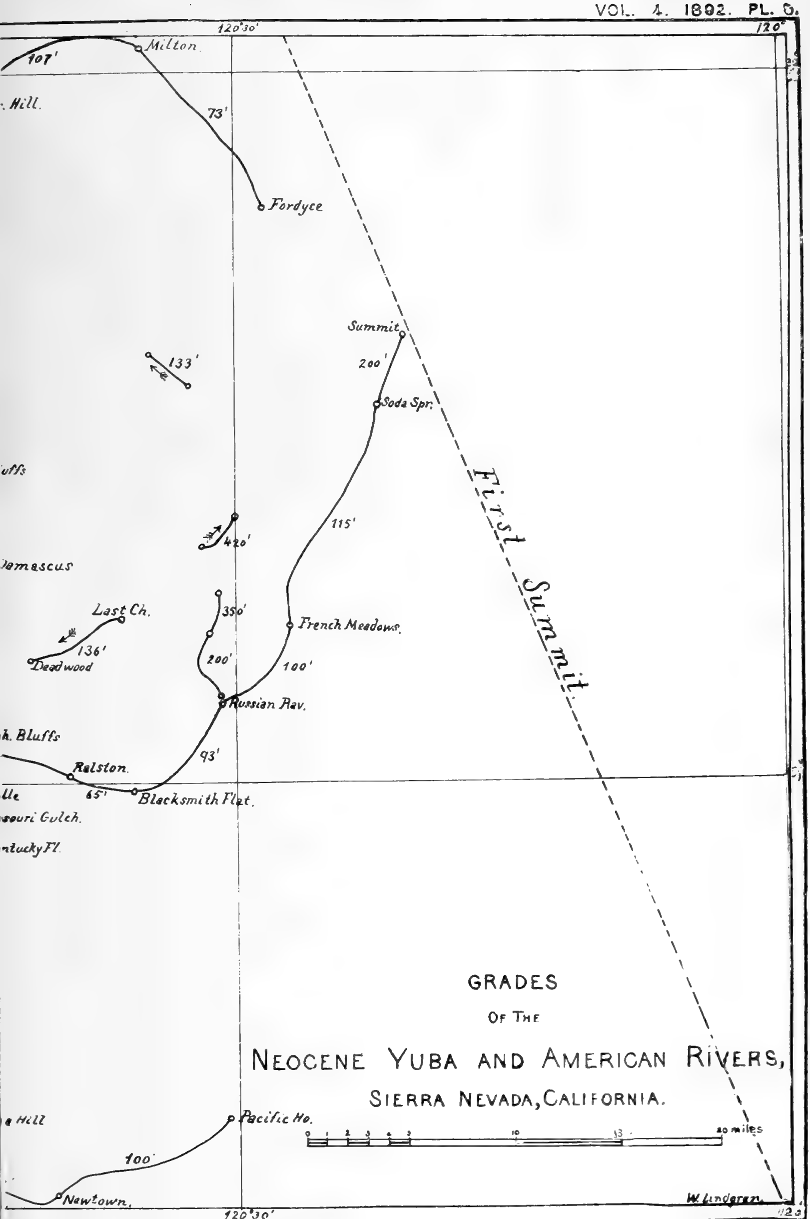
The help of a contour map is almost indispensable in order to obtain a correct idea of the Neocene drainage and topography.*

Each point of the contact lines between the bed-rock and the superjacent Neocene gravels or volcanic flows necessarily marks a point on the old surface of the region such as it was before hidden under Tertiary accumulations. A great number of these contact lines are usually exposed by the canyons and creeks eroded since the close of the Neocene period, and each of them affords a section through a part of the Neocene surface. It will easily be conceded that if the elevation of a sufficient number of points on the contact lines were known, a contour map might be constructed of the Neocene surface, showing the topography and elevation above the sea, provided that no change in level or tilting had taken place in the interval. Even in such a case the map would be valuable as showing the relative topography, and if the existence and amount of the disturbance of the old surface could be ascertained by other means a correct map referred to the old sea level might be obtained from it. The bed-rock points that have been above the surface of the lava flows since the end of the Neocene—and there are many of them in the Gold Belt region—have often suffered a degradation difficult to measure, but probably in most cases not large. The flat tops of many of them show them to have formed a part of the Neocene surface, and the erosion, while scoring and furrowing their flanks, has not yet reached their summits.

Many of the topographic features of the Neocene region may be directly read on the contour maps on which the geologic areas are outlined. If in a certain vicinity all the contact lines between lava and bed-rock run practically parallel with the contours and at the same elevation, the conclusion is easy that the Neocene deposit rested on a horizontal surface, provided no tilting has taken place since. If, again, the contact lines cross the contour lines in an irregular way and at considerable angles, the old surface was broken and irregular; with a sufficient number of contacts

* The part of the Gold belt here under consideration has been mapped on the scale of 1:125,000, or about two miles to the inch, with a contour interval of one hundred feet. It comprises the Smartsville, Colfax, Truckee, Sacramento, Placerville, and Pyramid Peak sheets, and the topography has been executed by Messrs H. M. Wilson, A. F. Dunnington, R. H. McKee, and M. E. Douglas under the charge of Professor A. H. Thompson. The geologic maps of the larger part of the area are finished and are now ready for publication. The Sacramento atlas sheet has just been printed.


121°30
121°
Indian H.
112'
Forest Cy.
Camptonville
76'
114'
91'
Orleans
87'
Snowpoint
137'
Moore's Ft.
Backbone
152'
Derbec
N. S. Juan
80'
Badger H.
115'
Relief.
158'
N. Bloomfield
16'
65'
Grizzly H.
0'
Blue Tent
Fr. Corral.
17'
78'
Lowell
136'
Sicard
Timb.
Hunt's H.
Liberty H.
100'
Mooney
0'
183'
113'
Red Dog
11'
227'
N. Red
125'(?)
Polar Star
Mallory
63'
Thompson H.
47'
Waloupa
76'
Litt. York
Indiana H.
40'(or less)
Iowa Hill.
(nearly level)
Wiscons. H.
19'
Mayflow
40'
20'
Bath.
Yankee Jim
52'
58'
Dardanelles.
90'
114'
Peckham H
57'
Jones' H
63'
Valley Line
66'
80'
Pilot Hill
32'
Lee Mine
Granite H.
21'
70'
Diamond Sprg
71'
121°



GRADES

OF THE

NEOCENE YUBA AND AMERICAN RIVERS,

SIERRA NEVADA, CALIFORNIA.

the general drainage system may be made out. In the case of an old valley running across a recent creek or canyon, the angles of the contact lines with the contour lines on the opposite sides of the present gorge will easily and directly indicate the ancient trough.

The accompanying map (plate 5) is reduced from atlas sheets of the United States Geological Survey. The elevations are partly taken from the very reliable observations of Messrs Pettee and Goodyear, partly from the maps of the United States Geological Survey, supplemented for short distances by my own aneroid determinations, and partly also from the surveys of Mr Browne. The channels where obliterated by erosion are marked by dotted lines; where remaining though generally hidden under volcanic masses, by heavy black lines. It must be understood that in both cases the indicated position is only approximately correct and showing the probable course of the deepest depression.

The grades given in plate 6 are affected by errors in distance and elevation. The latter are believed not to be great, but the former are difficult to ascertain. An attempt has been made in measuring the distance to follow the probable curves of the rivers; nevertheless the grades are probably all a little too steep on account of underestimating distances, but the differences are not, I think, large enough to be of much importance.

The sections in plates 7 and 8 are taken from maps used in the field on the scale of 1:62,500, or nearly one mile to the inch. In most cases it has been found necessary to enlarge the scale to 3,180 feet to the inch; only section *L L* is drawn on the scale of 6,360 feet to the inch. In all cases the vertical and horizontal scales are equal.

Outlines of Geologic History.

Topography.—In this latitude the Sierra Nevada has two summits, separated by the Truckee valley and the deep basin of lake Tahoe. The western summit, whose peaks rise from 8,000 to 10,000 feet above the sea, is also the divide between the Pacific and the Great Basin, while the Truckee river, draining lake Tahoe, has cut a deep canyon through the second or easterly summit on its way to the depressions of the Nevada deserts; on the eastern side of lake Tahoe the last-named summit attains even higher elevations than the principal divide. With the easterly summit and its escarpment this paper does not deal.

On the Pacific slope, in the watersheds of the Yuba and American rivers, one may roughly distinguish three provinces:

First, the foot-hill region, most frequently consisting of prominent ridges of diabase and amphibolite. Many of them, in Neocene times, projected boldly above the river beds, as shown, for instance, in the sec-

tion *A A*. In this province the volcanic flows are not conspicuous. It is probable that the higher parts of the foothill region remained above them, and erosion to a great extent removed them from the lower parts.

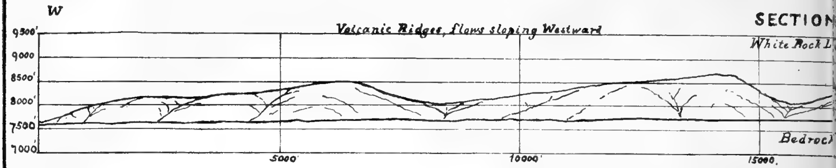
Second, the middle slopes, consisting chiefly of more or less altered sedimentary rocks, the auriferous slates. In this region the broad tables of Neocene lavas have largely effaced the pre-volcanic topography. Often, indeed, ridges of older rocks rise here also above the top of the gently sloping volcanic table-land, but as a rule they are not prominent.

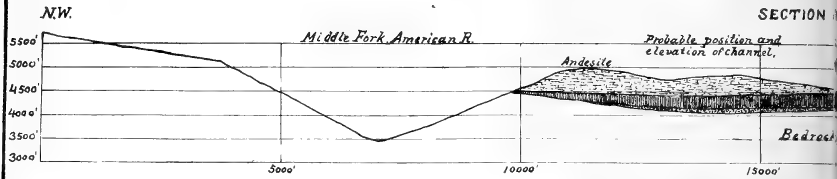
Third, the region of high bed-rock peaks adjoining the divide, in which the character of a table-land, frequently noticeable even here, becomes modified by prominent points of ante-Tertiary igneous and sedimentary rocks projecting conspicuously above the level of the Neocene flows. A glance at the map, on which only peaks of the older rocks are marked with their elevation in numbers, will make clear this distinction. At the divide there are many volcanic peaks, culminating in the extinct volcanoes of mount Lola, Castle peak and others which exceed 9,000 feet in height. The elevations of these volcanic peaks are not given on the map. Were the later volcanic masses removed along the divide the lowest passes would still be about 7,000 feet high.

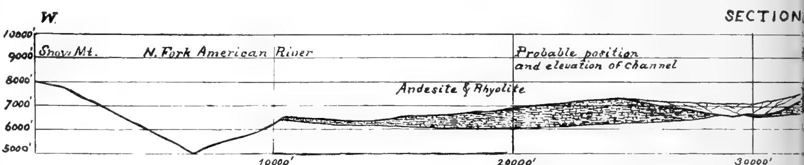
Condition of the Sierra Nevada before and during the gravel Period.—From the evidence accumulated it cannot be doubted that during the gravel period or the later part of the Tertiary the Sierra Nevada in this region formed a mountain range as distinct, if not as high, as at present. The two Neocene rivers headed near where the corresponding modern rivers begin now, in a region of lofty peaks and ridges. Their watersheds certainly did not extend further eastward than the first summit, and in fact corresponded pretty closely with those of the modern rivers. On the Truckee sheet, at least, the Neocene divide coincides very nearly with the divide of to-day, and only unimportant changes can be noted. East of the divide there was an escarpment of moderate slope, and which is now exposed in many canyons to a height of 1,000 to 2,000 feet; it probably was much higher than this, but below a level of from 6,000 to 7,000 feet above the sea its slope is completely hidden under the immense accumulations of lavas lying between the two summits north of lake Tahoe.

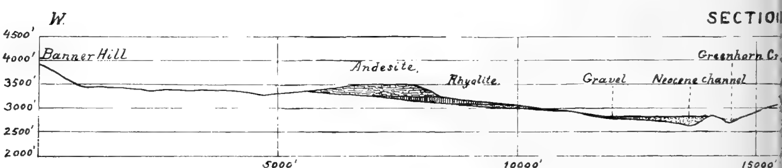
The total height of this escarpment as it was before the eruption of the Neocene lavas should perhaps be measured from the bottom of lake Tahoe to the summit of the western divide, approximately 4,000 or 4,500 feet. There is, on the Truckee sheet, no evidence of any important post-volcanic fault along the western summit, nor is there any decided evidence that the steep eastern slope just mentioned represents a fault formed shortly before or during the volcanic period.

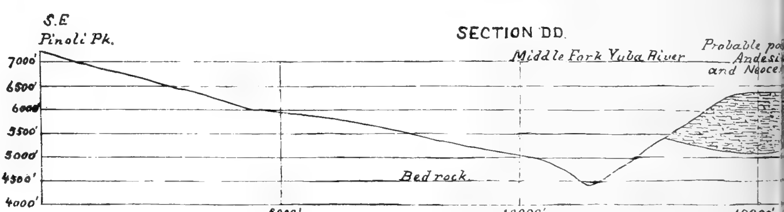
This is illustrated by sections *G G* and *L L* (plate 7). Many similar ones could be selected from the Truckee sheet. In *G G* a contact be-

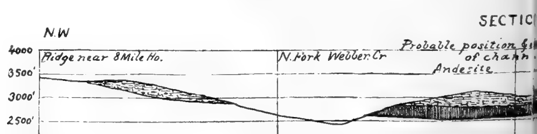

W
SECTION
Volcanic Ridges, flows sloping Westward
White Rock L
9300'
9000
8500'
8000'
7500'
7000'
Bedrock
5000'
10000'
15000.

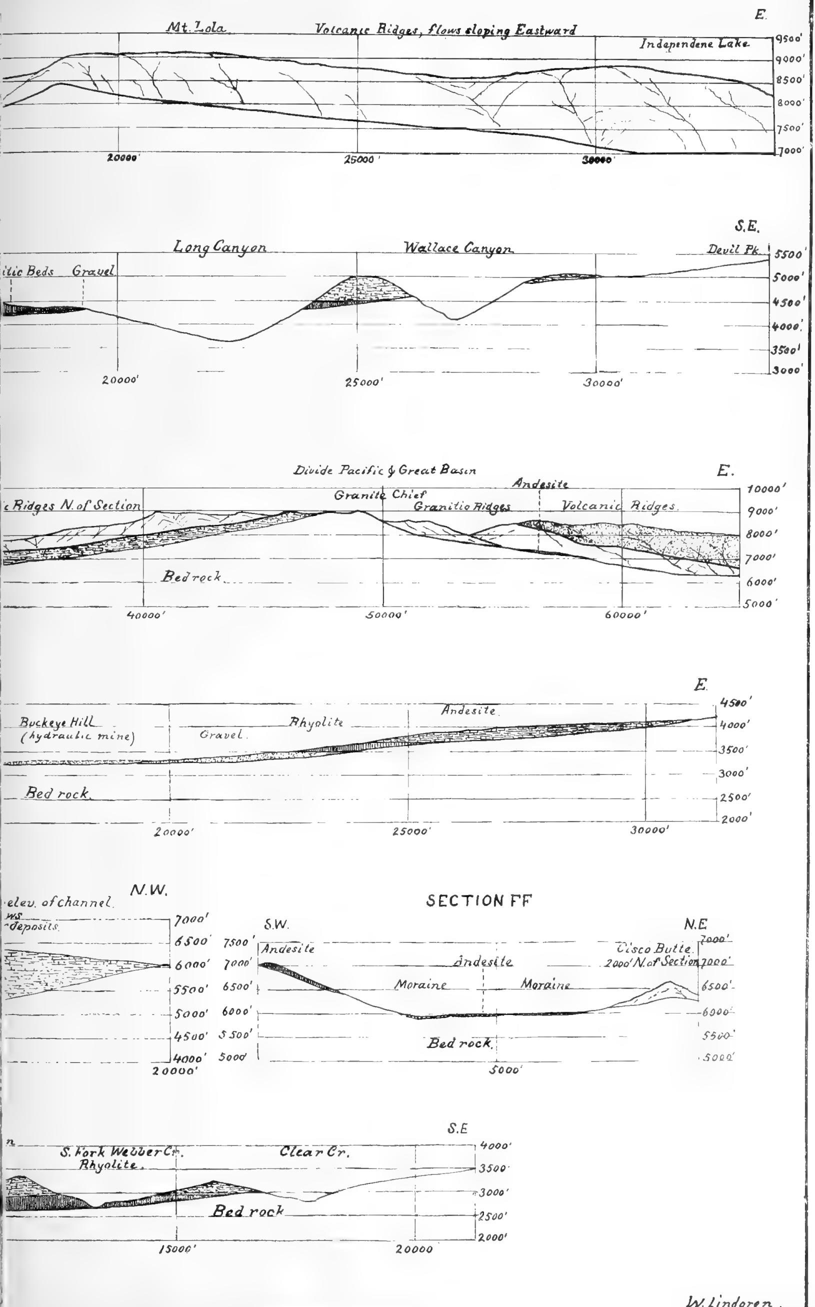

N.W.
SECTION
Middle Fork American R.
Probable position and elevation of channel.
Andesite
5500'
5000'
4500'
4000'
3500'
3000'
Bedrock
5000'
10000'
15000'


W.
SECTION
Snow Mt.
N. Fork American River
Probable position and elevation of channel
Andesite & Rhyolite
10000'
9000'
8000'
7000'
6000'
5000'
10000'
20000'
30000'


W.
SECTIO
Banner Hill
Greenhorn Cr
Andesite.
Rhyolite.
Gravel
Neocene channel
4500'
4000'
3500'
3000'
2500'
2000'
5000'
10000'
15000'


S.E
Pinoli Pk.
SECTION DD.
Middle Fork Yuba River
Probable po
Andesi
and Neoce
7000'
6500'
6000'
5500'
5000'
4500'
4000'
Bed rock.
5000'
10000'
15000'


SECTIO
N.W
Ridge near 8 Mile Ho.
N. Fork Webber Cr.
Probable position
of chann
Andesite
4000
3500'
3000'
2500'
2000'
5000'



E.
Mt. Lola
Volcanic Ridges, flows sloping Eastward
Independene Lake
9500'
9000'
8500'
8000'
7500'
7000'
20000'
25000'
30000'
S.E.
Long Canyon
Wallace Canyon
Devil Pk.
Gravel
5500'
5000'
4500'
4000'
3500'
3000'
20000'
25000'
30000'
Divide Pacific & Great Basin
E.
Andesite
Granite Chief
Granitic Ridges
Volcanic Ridges.
Ridges N. of Section
Bed rock
10000'
9000'
8000'
7000'
6000'
5000'
40000'
50000'
60000'
E.
Andesite
Rhyolite
Buckeye Hill
(hydraulic mine)
Gravel
Bed rock
4500'
4000'
3500'
3000'
2500'
2000'
20000'
25000'
30000'
N.W.
elev. of channel
deposits
7000'
6500'
6000'
5500'
5000'
4500'
4000'
20000'
SECTION FF
S.W.
N.E.
Andesite
Andesite
Moraine
Moraine
Cisco Butte
2000' N. of Section
Bed rock
7500'
7000'
6500'
6000'
5500'
5000'
5000'
S.E.
S. Fork Webber Cr.
Rhyolite.
Clear Cr.
Bed rock
4000'
3500'
3000'
2500'
2000'
15000'
20000
W. Lindgren.

tween granite and andesite along which the section is laid runs for many miles nearly due eastward across the divide, thus exposing an excellent profile of the Neocene surface. The high volcanic ridges of mount Lola immediately northward are projected on the section. The slopes of the flows are eastward and westward from the central vents of the old volcano of Lola.

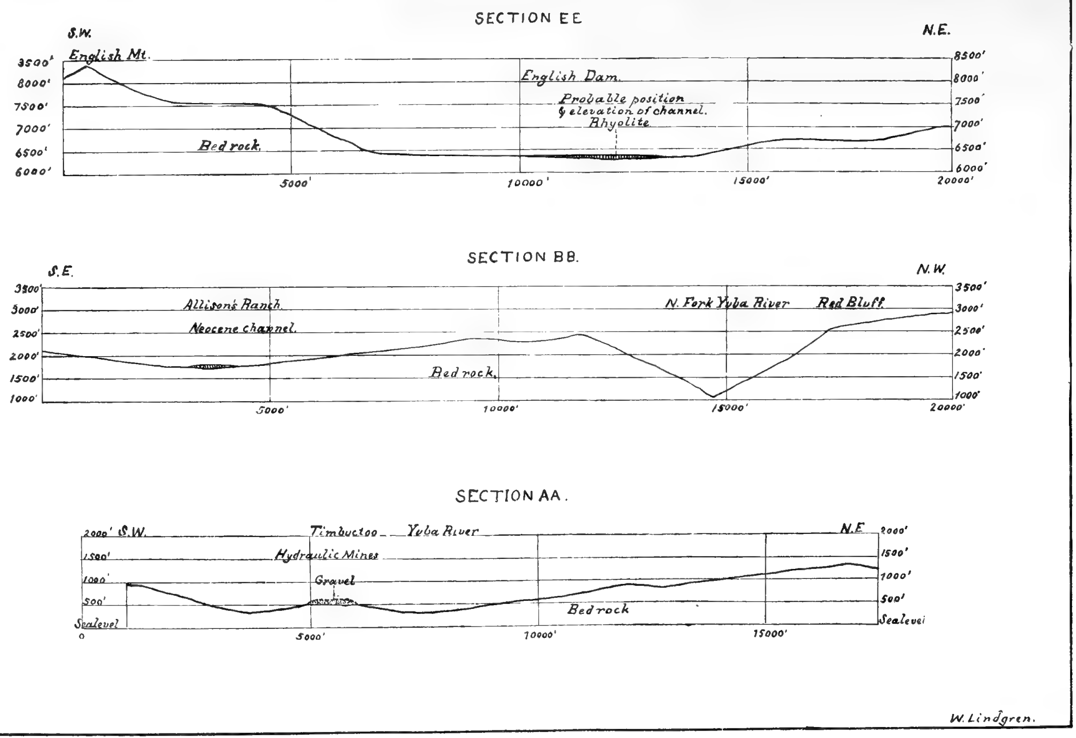
In *L L* a section is made on a smaller scale across the divide showing the depression of the headwaters of the Neocene middle fork of the American river, east of which rises the old divide at Granite Chief. The river heads only a few miles northward and rises rapidly in this direction.

The decided slope eastward from Granite Chief should be noted. That this slope was also that of the Neocene divide is proved by the contact lines of the andesitic masses with the underlying older rocks. This line is projected on the section from the ridges immediately north of it.

From the rugged country in the region of their sources the rivers pursued their course down in broad valleys separated by ridges which even in the lowest foot-hills sometimes reached an elevation of a thousand feet above the channels. The outlines of the ridges were usually comparatively gentle and flowing; still, slopes of ten degrees from the channel to the summit were common and slopes as high as fifteen degrees occurred in the eastern part of the Sierra. The character of a region of old and continued erosion, commencing probably far back in the Cretaceous period, is everywhere plainly evident. In the center of the deep depressions is quite frequently found a deeper cut or "gutter," indicating a short period of more active erosive power just before the beginning of the gravel period. At this time, probably about the beginning of the Miocene period, the streams became charged with more detritus than they could carry and began to deposit their load along their lower courses, especially at places favorably situated, as, for instance, along the longitudinal valley of the South Yuba. Toward the close of the Neocene, gravels had accumulated all along the rivers up to a (present) elevation of about 5,000 or 6,000 feet; above this it is plain that erosion still continued in places with great activity and furnished some of the material deposited in the lower parts of the streams. The coarse character of much of the gravel and the often remarkable absence of fine sediments in the beds point clearly to a somewhat rapid stream capable of carrying off a great deal of silt, and the accumulations are probably due to rapid overloading rather than to low grade of the rivers. The deep channels were filled and the gravels encroached on the adjoining slopes, where they were deposited in broad benches. A maximum thickness of 500 feet of deposits was attained on the South Yuba, and of from 50 to 200 feet in the other parts of the lower rivers. In the lower and middle Sierra some

of the rivers then meandered over floodplains two or three miles wide, above which the divides of bed-rock rise to a height of several hundred feet. In some instances low passes over divides were covered, and temporary bifurcation and diversion of rivers into adjoining watersheds occurred.

The volcanic Period.—At this time the first eruptions of rhyolite began from the first summit, from the volcanic center of Castle peak, they poured down the valleys, at first as molten flows, then as fine breccias and tuffs, and, being mixed with detrital material on their way, they are finally found lower down as semi-volcanic sands, clays and gravels. These beds of mixed volcanic and sedimentary character, usually fine-grained and distinguished by a brilliant white color, have been collectively distinguished under the name of rhyolitic beds, and merge into the tuffs and massive rhyolites of the upper valleys. The rhyolitic flows usually confined themselves to the valleys and only in some instances flooded certain of the low passes. The maximum thickness of these flows near the summit is one thousand feet, but it rapidly diminishes westward. These masses of fine detritus flooded the lower slopes and compelled the rivers to seek new channels, still, however, in general confined to the old valleys. The waters at once began the work of cutting down in the clayey and sandy masses. Then the period of the andesitic eruptions began. Dark-colored mud flows, at first sandy and clayey, again flowed down the valleys; the divides began to be covered. Again the rivers were displaced and again they at once began their work of active erosion, cutting down not only through the accumulated silt to their former levels, but, wherever the intervals between the eruptions allowed it, down through the gravels sometimes deep into the underlying bed-rock. In some districts, especially on the American river, these intervolcanic channels cut and destroyed again and again the older deposits, pursuing a wholly independent course, although in general flowing in the same valleys. They have exactly the same characteristics as the modern rivers. It is important to note that they enable us to fix with accuracy the relative date of the change from the conditions of the Neocene to the conditions of to-day. Whatever causes produced this change, they began to act at this time. The intervolcanic channels were of an ephemeral character; successive eruptive flows changed their direction, and it is to be expected that there were, as shown by Mr Browne, several different systems of them. They occur principally in the watersheds of the American river where the interval between the first and the last andesitic flows seems to have been considerably larger than in the region of the Yuba. Cement channels, as the intervolcanic channels are often called, no doubt also occur in the latter, but as a rule they did not have time to cut down far into the rhyolitic beds before they were filled and replaced



Sections Showing Neocene Drainage Systems

by the last great andesitic flows. The intervolcanic channels, being no part of a permanent and established drainage, are not described or further discussed in this paper.

These last flows, coming down in rapid succession from the volcanoes of Weber lake, of mount Lola, of Castle peak, and many others southward, flooded everything and covered up the lower and middle slopes to such an extent that only isolated peaks or ridges protruded above them. Their character is peculiar; they consist of a gray or brown tuffaceous breccia, containing, in the foot-hills as well as in the high range, large, usually angular, bowlders of andesite. They came down the slope as successive mud flows, setting soon to a hard and compact rock. Molten andesitic flows are found in the lava-flooded valley between the two summits, and also at some places west of the first summit, but they did not extend far down the western slope.

The thickness of these flows ranges from over a thousand feet high up to fifty or one hundred feet down toward the plains, where they are nearly always underlain by volcanic sands and conglomerates washed down from earlier flows which had not reached so far down.

The eruption of this tuffaceous breccia is assumed to close the Neocene period, and its flows form an important horizon by means of which the Neocene gravels may be separated from the later Pleistocene accumulations. The age of the flows is indicated by the numerous plant impressions common in the clays of the rhyolitic beds, as well as in those of the older underlying gravels, and which, as well known, distinctly point to the Neocene period. Only rarely is there any difficulty experienced in distinguishing the Tertiary from the Pleistocene gravels.

The length of the volcanic period may be roughly measured by the depths of the "cement channels" on the Forest hill divide. They have cut through about one hundred and fifty feet of loose detritus and, at most, one hundred feet of solid rock—not much more than a twentieth of the erosion since the close of the volcanic period.

There have been no andesitic eruptions of later date than those described in the region now discussed, and the continuity of the last overwhelming lava floods can be traced, almost uninterruptedly in places, from the plains of the great valley to the summits of the high Sierra.

When the volcanic activity ceased * the rivers began to seek their final channels, those of to-day. The general drainage was outlined by the

*An eruption of massive basalt occurred in some parts of the Sierra Nevada subsequently to the andesitic eruptions and previously to the glaciation. In the region here considered only small areas of this Pleistocene basalt are found.

Mr H. W. Turner has recently shown (Am Jour. Sci., 3d ser., vol. xliv, 1892, p. 455) the existence of a basalt antedating the andesite in the northern part of the Sierra Nevada. This earlier basalt does not occur in the area described in this paper.

ridges of older rocks still rising above the flows, and to them is to be attributed the fact that the Neocene river system roughly corresponds to the present one; but over the large stretches of volcanic tables the rivers marked their new courses entirely independent of the older streams, now following them, now crossing them in a most irregular manner.*

The Neocene Yuba River.

THE MAIN RIVER.

From the Sacramento Valley to French Corral:—At Smartsville, near Sacramento valley, a stretch of channel three miles long has been preserved. Its character and grade are described in detail by Mr Pettee in the "Auriferous gravels," pp. 379–383. At Sicards flat, about two miles lower down, on the northern side of the river, a fragment of the old channel remains, and three miles further down, on the southern side of the Yuba, the last trace of it is found, but it is not certain whether the elevation given at the last place represents the lowest channel. From here on it is buried under the more recent deposits of the great valley. It should be noted, in this place, that the areas of auriferous gravels indicated by Mr Pettee on the low rolling foot-hills west of Smartsville as Neocene and below the volcanic flows are in reality Pleistocene and rest on the andesitic breccia, and that they consequently have no significance in tracing the Tertiary channel.

The gravels at Smartsville and Sicards flat do not belong to the oldest Neocene deposits, for they contain a considerable amount of andesitic pebbles. They are, however, certainly Neocene, for at Smartsville they are covered by that sheet of andesitic tuffaceous breccia which, in the region under consideration, marks the close of the Neocene period. They must represent the Neocene river in its lower course, for both north and south of Smartsville rise bed-rock ridges, and this place affords really the only outlet possible for the channels of the upper course of the Yuba; the Neocene river broke through the barrier of the great diabase area of Yuba county in a valley or canyon of somewhat gentler profile, but almost as accentuated as that of the recent river. The ridges on each side rise to a height of one thousand feet or more above the old channel (see section *A A*). It might be objected that the channel at Smartsville was deepened during the intervolcanic period of erosion, and consequently no longer represents the bed of the prevolcanic river.

* In the region described postvolcanic faults are rare; those found have seldom more than 10 or 15 feet throw. The Tertiary deposits would greatly facilitate the recognition of any such faults of considerable throw, and I think the probability very slight that the slopes shown in the sections are to any noticeable degree influenced by such postvolcanic disturbances.

This I do not think is compatible with the gentle curve made by the bottom of the old channel. The intervolcanic erosion cut sharp, steep canyons like those of to-day. The deepest "gutters"* in the Smartsville channel might perhaps have been carved by it and it probably swept away earlier accumulations of "white" or quartz gravel. From Smartsville to French Corral there is only one way which the Neocene river could have followed, that of the present river canyon; any other way would necessitate extremely improbable and sudden changes of grade. A scattered line of small deposits indicates that in all probability the old river, near the mouth of Deer creek, received a tributary of which one branch came from Nevada City and the other from Grass valley.

Grades:

Lowest point—Sicards flat, $3\frac{1}{2}$ miles, 60 feet per mile (?).
Sicards flat—Timbuctoo, $1\frac{3}{4}$ miles, 100 feet per mile.
Timbuctoo—Mooney flat, 3 miles, 113 feet per mile (Smartsville channel).
Mooney flat—French Corral, 10 miles, 78 feet per mile.

The Nevada City and Grass Valley Channels.—In spite of the extensive erosion west of Nevada City and Grass Valley there is pretty good evidence that the channels of these places formed the old equivalents of the present Deer creek and connected with the main Yuba river a short distance above Mooney flat, three miles above Smartsville. The Nevada City channel evidently headed a few miles east-northeast of that city in the Harmony ridge, and is exposed in the East Harmony and West Harmony drift mines; † it runs westward with a steep grade, and, curving southward, emerges east of the Sugarloaf, in the old Manzanita diggings, and thence passes on to the hydraulic mines northwest of the city (American hill). From here on it is largely eroded away. The large amount of gravel in the lower part of this channel is remarkable. The low divide toward the main river eastward formed a gateway through which some of the rhyolitic tuffs poured down toward Nevada City.

Grades:

Manzanita—West Harmony, about 76 feet to the mile.
West Harmony—Harmony, about 190 feet to the mile.

The Grass Valley channel is somewhat different in having a comparatively small amount of gravel. It is covered with tuffs and volcanic sands, above which, as usual, lies the compact tuffaceous andesitic breccia. It is separated from the Nevada City channel by a four-hundred feet high bed-rock ridge, culminating in Banner hill. The first point where

* "Auriferous Gravels," p. 380.

† These mines have been developed since Mr Pettee's visit to the place.

it is met with is at the "Buena Vista slide,"* a few miles east of Grass Valley; it is here covered by heavy masses of rhyolitic sand and tuffs—an overflow from the main South Yuba channel; from here it passed by Kres and Union hill across the eroded gap of Grass Valley, and thence on through the volcanic ridge down to Rough and Ready. The possibility is not excluded that this Grass Valley channel belongs to a somewhat later period than that of Nevada City.

Grades:

The average grade from the Manzanita diggings to supposed junction with the main Yuba near Mooney flat, 16 miles, is 115 feet to the mile.

The same from Buena Vista to the same junction, 16 miles, is about 122 feet to the mile.

The actual grade of the Grass Valley channel from Buena Vista slide to Rough and Ready is about 72 feet per mile. This necessitates a heavy fall for the lower part of the Neocene Deer creek.

French Corral to North San Juan.—Between these two points the channel is nearly continuous, and the volcanic beds once covering the gravel are almost completely eroded. This part of the channel has been described in detail in "Auriferous gravels," page 196 et seq. and page 385 et seq., and also previously to this by Mr J. D. Hague.† Attention should be called to section *B B*, which excellently illustrates the topography of the ancient valley. It is seen that, without allowing anything for subsequent erosion, the northwestern side of the valley rose 1,300 feet in a short distance; it culminated in the (not shown) Oregon peak, a high diabase ridge 1,700 feet above the channel.

Grade:

From French Corral to North San Juan the grade is pretty regular and averages, in 7 miles, 65 feet per mile.

North San Juan to Badger Hill.—In seeking to trace the Neocene river further up the slope from North San Juan there are only two places which can be connected with it. The one which doubtless indicates the continuation of the main channel upward is Badger hill. The stream, of which we find the outlet at Badger hill, must in fact have connected with San Juan; high bed-rock bars any other way. This has been universally recognized by all investigators of the region.

Grade:

North San Juan to Badger hill, 4½ miles, 80 feet per mile.

* The elevation of the bed-rock at this place is somewhat doubtful on account of sliding masses of clay and sand; it is probably not far from 2,750 feet.

† The Water and Gravel Mining Properties belonging to the Eureka Lake and Yuba Canal Company, 1876.

THE NORTH FORK.

Another series of auriferous gravel deposits which can be connected with North San Juan begins at Camptonville. That this is extremely probable has been sufficiently pointed out by Mr Pettee.* I may add that here, too, high bed-rock on either side of Oregon creek prohibits any other outlet excepting that cut by the modern canyon.

From Camptonville this Neocene stream, which corresponds to the present North fork, continued to Depot hill by way of Galena hill and Weeds point (p. 428), and then undoubtedly connected with Indian hill, on the brink of the North Yuba canyon. Near this point it probably forked again, the more important stream crossing the present North fork to Brandy City and Council hill and continuing up toward La Porte and Gibsonville. This branch of the old river will not be followed any further northward in this paper. Toward its sources, near the center of volcanic activity in Sierra and Plumas counties, evidences of disturbances of the gravel beds by faulting became very frequent.

At Depot hill the Neocene stream flowed through a canyon, the walls of which rose about eight hundred feet on the western side and one thousand feet on the eastern side, with a slope of ten or eleven degrees.

Grades:

North San Juan to Camptonville, 91 feet per mile (from a supposed point of junction one and a half miles above North San Juan).

Camptonville to Depot hill, 3½ miles, 135 feet per mile.

Depot hill to Indian hill, 1 mile, 100 feet per mile.

Depot hill to Brandy City, 3 miles, 126 feet per mile.

THE MIDDLE FORK.

Badger Hill to North Bloomfield.—It has never been seriously questioned that there is a continuous channel between these points; its lower course is approximately outlined by the gravel area extending between Lake City and Badger hill by way of North Columbia and Cherokee. The gravel beds here attain the enormous thickness of five hundred feet, and up toward Lake City become covered by thick deposits of clays and volcanic flows.

Grade:

For reasons stated later on it is not probable that there is an even grade between North Bloomfield and Badger hill. It is altogether more probable that for the first four and a half miles from Badger hill the grade is very gentle, about 14 feet per mile, and that the steeper grade of the North Bloomfield channel begins at a point somewhat east of

* Auriferous Gravels, p. 428.

North Columbia; this grade would be approximately 158 feet per mile in a distrance of 3 miles, an extraordinary contrast indeed. Mr Pettee* assumes an even grade of 72 feet per mile.†

North Bloomfield to Snow Point.—There has been a belief prevalent for a long time that the Bloomfield channel connects eastward with the Woolsey flat, Moores flat, and Snow Point areas. The line of connection is given by Mr Pettee‡ as being via the Derbec and Watts shafts, and necessitates the very improbable grade of 290 feet per mile between North Bloomfield and the latter place, while the grade between Watts shaft and Woolsey flat would only be 60 feet per mile. Mr Pettee thinks faults or rapids might possibly occur some distance east of North Bloomfield.

As to the Derbec shaft, it certainly is not on the main channel; neither is it very well possible that the Watts shaft is, for there is an inlet north of Backbone house which is considerably lower than the lowest point in the Watts channel (3,800 feet). At this point there is a steep lava bluff underlain by heavy masses of clay; enormous slides have taken place, obscuring the relations of the strata, and the lowest bed-rock point is not easily ascertained with precision. My elevation for this point was made with an aneroid from the known elevation of Backbone house directly above; the lowest bed-rock point would be about 700 feet below the Backbone house, and the elevation 3,400 feet, with a probable error of 50 feet. This is just above the point where Bloody Run makes a sharp turn to the east; on both sides of the creek north of this inlet there are benches of gravel at least as low down as 3,500 feet, indicating plainly, with their bed-rock rising eastward and westward, that a new eroded channel once occupied the space between them. From here the Bloomfield channel must have curved eastward and followed the present canyon up to near Woolsey flat, where it again made a bend southward. The gravel exposed on the opposite side of the Middle fork of the Yuba on the ridge between Kanaka creek and the river at an elevation of 4,000 feet, with rising bed-rock northward, lends additional strength to this view. Watts shaft in all probability only represents a tributary to the main river.

From Woolsey flat the continuation of the channel is very distinctly indicated by Moores flat, Orleans and Snow Point, as pointed out by Mr Pettee;§ at Orleans and Snow Point the stream flowed in a comparatively steep, narrow valley. The bed-rock immediately to the south

* Auriferous Gravels, p. 392.

† Mr Pettee's distances vary somewhat from those here adopted, which I have endeavored to measure along the probable curves of the stream.

‡ Auriferous Gravels, p. 399 et seq.

§ Auriferous Gravels, p. 203.

of these points rises in a short distance 700 feet above the bottom of the channel.

Grades:

North Bloomfield to Backbone inlet, 3 miles, 152 feet per mile.

Backbone inlet to Moores flat, 4½ miles, 137 feet per mile.

Moores flat to Snow Point, 2¼ miles, 87 feet per mile.

The Derbec Channel.—The Derbec shaft is sunk on a very different channel from that of North Bloomfield; it pays for drifting, which the main channel does not, as a rule, and it carries a great many granite bowlders, which I think are derived from a hidden area under the volcanic flows rather than carried down from the granitic area above Washington. It has been mined for a distance of 3,500 feet in an easterly direction from the shaft. It represents a tributary to the main channel, and I think it very probable that it connects under the lava with the Relief inlet. Its course from there upward is very uncertain, as so much of it has been eroded. A connection with the Omega gravel area and others below that on the brink of the South Yuba canyon seems quite probable, but the problem is complicated by the existence of the deep Centennial channel on the Washington ridge, and more investigations are necessary before a final result can be reached. On the other hand, the Derbec channel undoubtedly joins the main channel at some place between North Bloomfield and the Backbone house.

Grades:

Derbec shaft to Relief, 3 miles, 115 feet per mile.*

From the Derbec shaft down to the main channel there is a pretty heavy grade of about 120 or 150 feet to be accounted for, but the distance, allowing for some curves, might have been nearly one mile.

The Forest City Channel.—The channel between Orleans flat and Forest City is sufficiently known from Mr Pettee's notes.† Above Forest City the Neocene valley is continuous as far as City of Six, overlooking Downieville. From here it is not easy to trace it any further.

Between Forest City and the Ruby mine there is, however, a break in form of a mass or dike of volcanic rock. At the Ruby mine there are two channels, one lower connecting with the City of Six, and one upper running toward Forest City. The Bald Mountain Extension is mining a tributary from the northeast. In its former tunnel a basalt dike was found cutting across the andesitic breccia and showing that the eruption of the basalt masses of the Forest hill table mountain took place in this vicinity.

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* Auriferous Gravels, p. 405.

† Ibid., p. 433 et seq.

Grade:

From Orleans flat to Forest City, 5½ miles, 70 feet per mile.

Snow Point to Milton.—Mr Pettee regarded it as improbable that any stream ever came down to Snow Point from an easterly or northeasterly direction,* and evidently considered the Forest City channel as the main Neocene Middle Yuba. He states, regarding the country to the northeast of Snow Point,† that "it is thought by some that a channel will be traced from Haskell peak by way of Chips hill (near Sierra City) to a junction with another channel coming from a more easterly direction, and that the two united follow a course under the lava by way of American hill and Nebraska to some point near Forest City. . . . Others think that the high channel followed an independent course toward the south and crossed the line of the present Yuba river near Milton without making any connection at all with the lower channel, which passes by Forest City." Mr C. W. Hendel, who is intimately acquainted with the mining industries of Sierra and Plumas counties, appears to have been the first to announce the former view as long ago as 1872,‡ but he carries his channel down from Plumas county by Beckwith pass and Gold lake somewhat regardless of grades and intervening bed-rock ranges.

Mr Pettee states that his examination was hardly sufficiently extended to warrant the expression of any decided opinion, but that, while he was not ready to assert that there were no old gravel channels, he did not think it proved that any existed in this vicinity.§

The careful examination of the country between American hill and Milton cannot fail to convince any one of the existence of a decided trough or depression below the lava, so deep as to justify the conclusion that it represents the principal Middle Yuba during Neocene times.

The outlet of this channel is undoubtedly found at or near American hill, on the southern bank of Wolf creek, while Nebraska and the gravels between the forks of Wolf creek represent tributaries to the main river. The gravel banks exposed at Bunker hill (near American hill) are about three hundred feet high, and the deep trough-like channel is clearly indicated. From the outlet at American hill there is hardly any other course possible, down stream, than across the eroded canyon of the Middle Yuba toward Snow Point. That a large channel ever passed across the Graniteville gap at Shand's hotel is, for a great number of reasons, not at all likely. The elevation of this gap is 4,625 feet.

For at least ten miles above American hill the channel is hidden under the lava flow on the north side of the Middle Yuba. On the north-

* Auriferous Gravels, p. 401.
† Ibid., p. 442.
‡ Ibid., p. 210.
§ Ibid., p. 442.

western side the bed-rock is very high, sometimes forming the crest of the divide between the North and Middle Yuba. On the other hand, the lava bed-rock contact runs very low on the slope of the canyon side, while it rises to considerable elevations on the opposite, southeastern side of the river. This relation is clearly illustrated in section *D D* (plate 7). For a long distance above American hill there is no indication that the channel passes out from under the lava into the eroded canyon. Supposing a fairly uniform grade from Milton to American hill, it cannot emerge until about nine miles from Milton, and very possibly less. At any rate, the old channel for many miles above American hill would appear to offer an excellent field for drifting operations. It is easily accessible from the canyon of the Middle Yuba by moderately long tunnels, which, for instance, at the section *D D* would probably have to be placed at an elevation of 5,000 feet. It is quite likely that the gravel in this channel would pay for drifting, especially as it would have received the débris from a part of the quartz mines south and southwest of Sierra City. An attempt to open up this channel was made at the Savage tunnel, about four miles above American hill, but it was abandoned long before completion.

Attention should be called to the deep valley through which the section shows the channel to have flowed. Those accustomed to profiles of equal horizontal and vertical scale will readily recognize the abrupt slopes of its sides. It is not probable that Pinoli peak has suffered any large degradation since the Neocene times, as andesitic flows cover it on the eastern side almost to the top.

High bed-rock continues on the divide north of the Middle Yuba up to Milton, while the lava runs far down on the northern canyon slope. The detailed investigations in this region have not yet been completed, and just where the channel leaves the lava flow and follows the eroded course of the present river is not quite certain. Neither to the north nor to the south is there, however, as far as I am aware, any possible outlet by which it could have turned from this course until Milton is reached.

At Milton, however, there are both north and south of the Middle Yuba places with sufficiently low bed-rock to allow the Neocene river to deviate from its course parallel to the river. The first is about a mile southeast of Milton and forms the distinct outlet of the subsequently described Milton-Meadow lake channel; its elevation is not far from 5,950 feet. The second is northeast of Milton, where a gap appears to exist, with rapidly rising bed-rock on both sides. The approximate elevation of this gap, which I do not know from personal inspection, has been determined by Mr Pettee to be 5,938 feet.* It would seem to rep-

*Auriferous Gravels, p. 442.

resent a tributary coming down from the vicinity of Haskell peak. The high bed-rock ridges near Haskell peak, the northern side of which have been examined by Mr H. W. Turner, preclude, except by assuming very large subsequent disturbances, any supposition that a channel could have flowed northward from Milton.

Grades:

American hill to Snow Point, 4½ miles, 114 feet per mile.

American hill to Milton, 11 miles, 107 feet per mile.

Milton to Meadow Lake.—Between these two places, a distance of 11 miles, there exists a deep channel entirely covered by volcanic rocks. It is easily traceable by means of a lower flow of rhyolite and by means of conspicuous bed-rock ridges rising on either side. The highest of these is English mountain, through which the section *E E* is laid. It shows that in some places, at least, the bed-rock peaks rise to a height of 2,000 feet above the ancient rivers.* The outlet of this channel is, as mentioned above, about one mile southeast of Milton, at the base of a high andesitic bluff underlain by rhyolite; it does not seem as if this rhyolite flow had extended much farther in a westerly direction from here. An attempt has been made to open the channel in this place; an old tunnel is still visible, but I do not know how the enterprise succeeded. Some coarse wash gold is said to have been found in this vicinity; there is no evidence of any considerable amount of gravel. So far up as this the old rivers probably did not accumulate much more gravel than the present streams do now in bars and stretches of slight grade. Whether the channel would pay for drifting is a doubtful question.

The distinct inlet of this channel is found between Fordyce and Meadow lakes at an elevation of nearly 6,700 feet. It is clearly indicated by the trough-shaped depression filled with rhyolite ("white lava") between the high granitic hills west of Meadow lake and the slate ridges of the main divide about two miles to the northeast. It would seem almost certain that this part of the ancient stream—east of Meadow lake—would be auriferous; the detritus from the Meadow lake quartz mines must have been swept down into this trough. Whether auriferous enough for drifting is another question. No gravel is visible at this point; moraines cover, however, a great deal of the ground here and obscure somewhat the relations between lava and bed-rock.

The course of the stream above this point is not known; its uppermost course has been swept away by the erosion of the North creek. High granite ridges rise southward and eastward; in fact we are now near the source of the Neocene river; the Neocene divide is only five or six miles

* A shoulder projecting from English mountain, which has been somewhat exaggerated in the drawing, produces the impression of a terrace. Such a terrace or bench does not exist in reality.

distant and its lowest passes eastward were at least one thousand feet higher than the stream at Meadow lake.

Grade:

Meadow lake to Milton, 11 miles, 73 feet per mile.

THE SOUTH FORK.

Badger Hill to Dutch Flat.—From Badger hill to Dutch Flat or Gold Run extends, about parallel to the axis of the Sierra, a series of extraordinarily heavy gravel deposits, largely denuded of their volcanic cap and especially adapted for mining by the hydraulic process. It formed a part of the old "blue lead," that mysterious stream which was formerly believed to have flowed north and south along the Sierra with a supreme disregard for grades and high slate ridges. The true relations of the deep channel in these deposits have been extensively discussed, especially in the "Auriferous gravels;" but Mr Pettee, who carefully examined the gravel mines along this line, was unable to form an opinion which could reconcile the apparently conflicting facts of grades and directions.

Mr Pettee stated* his belief that no deep channel will ever be found between Badger hill and Grizzly hill, but afterward suggested † that a connection existed between Blue Tent and Badger hill by way of Grizzly hill:

> "It seems most probable that this portion of the gravel field represents a broad estuary or lake-like expansion of water at the junction of two streams or where two streams by the filling up of their channels and the covering of the low intervening ridges became practically one. If this latter view is correct, it is not impossible that there may once have been a current from Grizzly hill toward Columbia hill even if the slope of the deep bed-rock is just in the opposite direction."

Mr Pettee‡ feels confident that no deep channel exists between Blue Tent and Scotts flat. He did not, however, examine the intervening ground. The continuity of the deep flat channel between Quaker hill and Dutch Flat is not denied, but he believes that there is also a deep channel with slight grade between Dutch Flat and Indiana hill, which would complicate matters greatly, for the channel at Indiana hill drains directly toward the deep channel of the Neocene American river.

After stating the facts based upon his excellent barometrical measurements, which I have extensively used in this paper, Mr Pettee says:

> "It does not seem possible that there was ever a deep channel flowing in either direction between Quaker hill and Indiana hill. Dutch Flat or Thompson hill must have stood at a parting of the ways, and it is very probable that there was another such parting between You Bet and Red Dog."

* Auriferous Gravels, p. 393.
† Ibid., p. 415.
‡ Auriferous Gravels, p. 413.

As a possibility, he mentions in another part of the volume* that the Red Dog channel may have found an outlet along the present Greenhorn river in a southwesterly direction.

The first question to be disposed of is whether or not there is a continuous channel between Dutch Flat and Indiana hill with a southward grade, as Mr Pettee thinks. It is admitted that there is a deep channel coming down along the Dutch Flat diggings, and that the elevation of this is 2,848 feet at Thompson hill. A short distance south of this, Squires canyon crosses the gravel area connecting Dutch flat and Indiana hill at an elevation of about 3,050 feet, or 200 feet above the bed-rock in the low channel of Thompson hill. Regarding the place Mr Pettee † says that "Where the gravel range is crossed by Squires canyon the country rock is seen on each side with a width of about 500 feet of gravel and tailings in the bottom of the canyon. How much more slate was visible before the accumulation of gravel began it is not easy to determine, but it appears as if the slate did not extend entirely across" . . . The result which I reached after two careful examinations was that the bed-rock does extend entirely across the supposed gap, and this effectually disposes of any deep channel connecting Dutch Flat and Indiana hill. The slate proper does not begin until further down the canyon. The bed-rock at the disputed place is the soft and decomposed gabbro of Dutch Flat, which in places looks very much like clay. There are a great many other considerations which favor the same result. The gravel areas of both Plug Ugly and Jehoshaphat hills between Squires canyon and Dutch Flat canyon have the distinct character of inclined benches above the main channel, through which benches a supposed connection southward could only have been effected by a deep and improbable gorge. Dutch Flat and Indiana hill were evidently separated by a low divide corresponding to the present American-Yuba divide. When the deep channel was filled up with gravel masses the stream began to deposit its load on the adjoining broad inclined benches. Finally even the divide was covered by the gravels, and a bifurcation might have taken place in the latter part of the gravel period by means of which some of the waters of the Yuba found their way over to the American watershed.

If the Tertiary deposits and flows were removed from the region between Dutch Flat and Badger hill an old longitudinal valley would be exposed to view with a high ridge rising both on the eastern and the western side. It cuts the strike of the probably Carboniferous clay slates and siliceous slates at a small angle. The lateral ridges are in part composed of harder siliceous rocks, in part of softer clay slates. The only out-

* Auriferous Gravels, p. 173.

†Auriferous Gravels, p. 153.

lets along this line westward are the narrow canyons cut by the present Bear, Steep Hollow, Greenhorn and South Yuba rivers. Through none of these canyons is there the remotest possibility that the ancient river passed westward. High bed-rock is exposed in each case on both sides of the gap cut by the recent rivers, and not even the smallest remains of any Neocene deposits are met with for some distance below any of the supposed gaps. Any such supposition would, moreover, necessitate extremely improbable and curious bifurcations. Along the whole line, Dutch Flat to Badger hill, there are gravels accumulated to an exceptional depth and extent. Above these gravels rest, at many places, the remnants of an eroded flow of rhyolitic tuffs and sands. They are first met with in Canyon creek, about five miles above Alta. They are exposed at Shady run, at Alta, at You Bet, at Hunts hill, at Buckeye hill and at Quaker hill. Again, they are exposed at Scotts flat, on the northern side of Deer creek, and, finally, at Blue Tent, where their volcanic character begins to be less apparent, being largely mixed with other detrital material; but everywhere they form a sheet perhaps a hundred feet thick and resting on several hundred feet of gravel.

The continuity and the direction of these flows of rhyolitic mud are distinctly and unmistakably indicated on the geologic map. Coming down the old channel along the upper course of Canyon creek, they flowed in a southwesterly direction, passing Alta and Dutch Flat, down to You Bet. Turning here with the valley, they flowed northward by Quaker hill to Blue Tent. Between Blue Tent and Badger hill the volcanic masses are completely eroded and the underlying gravel beds exposed.

Mr. Pettee traced the deep channel northward as far as Hunts hill, or even, with a somewhat uncertain elevation, to Quaker hill. If he had examined the relations at Scotts flat and the country between Scotts flat and Blue Tent, I am confident he would have arrived at the same conclusion which has been reached here. At Scotts flat there is the most ample evidence that a very large channel crosses Deer creek, with rapidly rising rim-rock on the east and west. The creek has not quite cut through the ancient river bed, the bed-rock being covered for a distance of nearly a quarter of a mile. The same accumulations of sands and tuffs as are exposed at Quaker hill are found abundantly above Scotts flat and in Rock creek between Scotts flat and Blue Tent. It has been shown that the deep channel as far as Hunts hill has no possible westerly or southerly outlet. High bed-rock all along on the western as well as the eastern side from here northward simply makes any other outlet than by Blue Tent impossible, if we do not assume entirely improbable faults of several hundred feet of throw. There is no point

by which any outlet by way of Nevada City and Grass Valley could be effected. The Harmony and Grass Valley channels are several hundred feet above the Quaker hill channel. There were, however, two low gaps in the ridge through which a part of the rhyolitic masses overflowed both down the Grass Valley and the Harmony channels (see page 269). From Blue Tent, where the deep channel is only 500 feet above the bed of the South Yuba, the direct continuation is given, as indicated by Mr Pettee, by the correspondingly low trough of the Grizzly hill channel on the opposite side of the river. Again, from here there is no possible low outlet except by Badger hill, and this way the Neocene river must have taken. Mr Pettee's own notes in regard to the former depth of the gravel at Spring creek confirm the existence of a deep channel beyond Grizzly hill.* In channels of slight grade such as this one, ups and downs of ten or twenty feet are very common. All these relations will appear much clearer on the geologic map which, it is hoped, soon will be printed.

If the deep channel between Blue Tent and Quaker hill would pay for drifting it would be a magnificent field for enterprise. Unfortunately, there are some doubts concerning this. The gold of extraordinarily heavy gravel beds is more commonly divided through the whole mass than concentrated on the bed-rock. However, drifting operations have been carried on with profit at You Bet, and it is not improbable that this part of the channel would pay well, at least in some places. It is said that an attempt to drift the deep channel at the Blue Tent outlet was not attended with success. The deposit would have to be opened up by long tunnels from the South Yuba canyon at Blue Tent, or east of that place.

Section *C C* is a typical one through the great Neocene South Yuba valley. On it may be noted the prominent bed-rock point of Banner hill—composed of diabase-breccia—and the andesitic and rhyolitic flows, as well as the upper gravel benches and the central trough or gutter. To one peculiarity of the rhyolitic flows attention should be called: although the flows descended the valley in a northwesterly direction and should present a level surface from east to west, still it is found quite generally that the eastern margin is higher by one or two hundred feet than the western. It is perhaps best not to attach too much importance to this as an indication of tilting, for in the first place a part of the flow was drained off through one or two lower gaps toward the west, and in the second place some erosion doubtless degraded the even surface in the interval between the rhyolitic and the andesitic flows.

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* Auriferous Gravels, p. 393.

Grades:

Wherever any parts of the deepest channel between Badger hill and Little York are exposed a very slight grade is almost invariably found to exist; it is so at Badger hill, Grizzly hill, Hunts hill, and You Bet. This is a pretty distinct hint as to the general character of the channel.

From Badger hill to Grizzly hill, a distance of six miles, there is a grade of sixteen feet to the mile. From Grizzly hill to Blue Tent across the South Yuba there is practically no grade. From Blue Tent to Hunts hill, a probable distance of eight miles, there is a grade of seventeen feet to the mile. At Quaker hill the value found by Mr Pettee, but which, according to him, is not quite reliable, was 2,650 feet, or 30 feet higher than at Hunts hill. It must be remembered, however, that great inequalities often exist in channels of gentle grade. In the Mayflower channel, for instance, Mr Browne has shown the existence of irregularities of twenty feet above and below the general grade. At Scotts flat the deep channel mentioned before has not been exposed. A shaft was sunk long ago in the creek which did not strike bed-rock until two hundred feet deep, at an elevation of 2,775 feet, but the channel below the level of the creek is about 2,000 feet wide and the probability of striking the deepest depression by a single shaft without drifting is very slight.

From Hunts hill to Red Dog the channel is practically level; neither is there any appreciable difference in level betweet Red Dog and Niece and West's mine at You Bet, a distance of about three miles, in which the deepest channel is hidden under heavy masses of gravel.* Between these last-named places several drift mines have been opened up, and in them, as shown by Mr. Pettee,† the deepest bed-rock is somewhat higher than at either end of the channel.

From the places there referred to as Heidliff's and Mallory's claims the bed-rock slopes down to Niece and Wests about 20 feet. Opposite Niece and West's mine is an isolated fragment of the deepest channel, known as "Waloupa," which place is again 30 feet lower than the bed-rock at Niece and West's. This makes a total length of about one mile in which the channel flowed in a nearly northeasterly direction. It is certainly interesting and worthy of notice that in this rare instance of a northeasterly direction the present grade of the Neocene channel should have the considerable slope of 50 feet to the mile in the opposite direction to that of the river in general, so that if the present grade were also that of the Neocene river it must at this point have flowed uphill for a dis-

* Mr E. C. Uren, of Auburn, has made a spirit-level survey along the surface between the two points and informs me that both have the same elevation.

† Auriferous Gravels, p. 166.

tance of one mile. The character of the gravel at this place is not different from that of adjoining parts of the old river. It must be admitted that this instance strongly suggests a deformation of the Neocene river bed by an increase of the westerly slope of the Sierra.

From Waloupa to Little York, a distance of one and a half miles, the channel has a grade of 76 feet per mile. The direction has now turned westerly.

From Little York to Dutch Flat, a distance of two and a quarter miles, there is a grade of 63 feet per mile.

It should be stated that there is no perceptible difference in the character of the bed-rock between the Quaker hill and You Bet part of the channel and the channel between Waloupa and Dutch Flat. The sudden increase in slope must be traced to other causes.

The Channel at Dutch Flat.—In the Dutch Flat channel a considerable rise of the bed-rock occurs and the width narrows. Large bowlders are found on the bed-rock and everything indicates a rapid current. This is partly explained by the belt of hard quartzite and gabbro across which the Neocene stream flowed at this place.

Grade:

In one mile, 227 feet.

The Liberty Hill Tributary.—This stream, which must have joined the main channel at the upper end of the Dutch Flat diggings, can be easily traced by way of Elmore hill, Liberty hill, Lowell hill and across Steep Hollow creek to Remington hill. From here its course has not certainly been determined.

Through the recent operations of a Gold Hill, Nevada, company at the Centennial tunnel and shaft the existence of a deep channel from Phelps hill southward has been proved. According to information obtained from the superintendent, Mr H. Richards, this channel, where at present met with in the tunnel, is wide and flat, and has a grade eastward of 75 feet to the mile. The channel exposed by the San José shaft is stated to be 60 or 70 feet higher than the first channel, and probably connects with it at some point further southward. There is, on account of high bed-rock, no possibility that the Centennial channel connects under the ridge with the Omega channel, and the probability seems to be that a continuous channel exists between Phelps hill and Remington hill, with a general north-and-south direction. If so, its grade must, on the whole, be slight, for Phelps hill is only 200 feet higher than Remington hill, which, with a distance of four or five miles, would give an average grade of 40 or 50 feet to the mile. The Centennial channel contains granite bowlders, which would seem to indicate that its headwaters were up in the granite

area above Washington. If this be the case, on the other hand, the Relief channel could not very well have connected with the Omega. Many complicated questions remain to be worked out in this vicinity.

In this connection mention might be made of the curious relations near mount Oro, a few miles east of Quaker hill. The same volcanic area that overlies the Phelps Hill-Remington channel covers this vicinity, but under it at mount Oro there appears to exist, if my information is correct, a depression which, as exposed by old inclines, is much deeper than the rims of the lava flow are at any place; it is at a lower elevation than both Phelps hill and Remington hill, and no possible outlet can be suggested.

Whatever the relations of the Centennial channel will ultimately prove to be, I think it probable that a fork of the principal channel continued from Remington, by way of Democrat and Excelsior, in a northeasterly direction under the volcanic cover for some distance up toward Omega.

Grades:

Upper Dutch Flat to Liberty hill, 1½ miles, 183 feet to the mile.

Liberty hill to Lowell hill, 3½ miles, 136 feet to the mile.

Lowell hill to Remington hill, ½ mile, 90 feet to the mile.

The Channel between Alta and Shady Run.—Cut off for some distance by Little Bear creek, the principal channel is found again emerging from under the volcanic cap at Nary Red, northwest of Alta. Some parts of this channel near Nary Red have been drifted. Near Alta two shafts have been sunk on it. In the one to the north of the railroad, according to information received of Mr E. C. Uren, of Auburn, bed-rock was reached at 200 feet and good gravel found, not rich enough, however, to pay for mining by shafts. At this point the main channel appears to have been joined by a tributary coming in from the west at the Moody gap, on the divide between Canyon creek and the American river and crossing Canyon creek south of Alta. The main channel continues, I have no doubt, under the lava cap up toward Blue Bluffs at Shady run, where it probably forked again, one fork, the deposits of which now are mostly eroded, continuing up toward the Neocene highlands near Cisco, by way of the isolated gravel area of Lost Camp, the other fork continuing for some distance up toward Blue canyon and Emigrant Gap under the lava ridge.

It would seem as if the deep channel from Alta up toward Blue canyon would offer a good field for mining enterprises.* The upper part of it is accessible by tunnels from the steep side of the canyon of the American

*Attention was some time ago, and very justly, drawn to the existence of this channel by Mr James F. Talbott, of Shady run, in a series of articles in the Mining and Scientific Press of June 14, 1890, et seq., vol. 60, No. 24, et seq.

river and the lower part by tunnels from Nary Red, or from certain parts of Canyon creek. It is doubtful whether this channel extends up to Emigrant Gap. The relations of the bed-rock to the lava at this place lead me to believe that it is rather the Omega channel, which extends up by Bear Valley house, near Emigrant Gap, and from there connects with the short distance of channel clearly indicated some distance south of Cisco. The steepness of the sides of this channel, which is remarkable, is illustrated in section *F F*. In a distance of three miles it has a grade of four hundred feet, or 133 feet to the mile. The channels above Emigrant Gap do not, I think, carry gold enough to make their exploitation profitable.

Grades:

Dutch Flat to Nary Red, one mile, about 225 feet.

Nary Red to Blue Bluffs, four miles, about 125 feet to the mile. The bed-rock at Blue Bluffs slopes in toward the ridge.

The Neocene American River.

Ridges of older rocks separated the watershed of the Neocene American river from that of the Yuba. The North fork of the American drained the region of Forest hill, and its sources are found near Summit valley, at the crest of the range. The South fork drained the Placerville region, and it appears to have headed among the peaks south of lake Tahoe. Only part of the latter drainage system has been mapped.

THE SOUTH FORK.

From the Sacramento Valley to Diamond Springs.—The accumulations along the lower part of the Neocene American river are to a very great extent destroyed by subsequent erosion, and to reconstruct that part of the river is consequently not very easy; moreover, it has only a theoretical interest, since nearly all of the auriferous gravels along it are swept away. In discussing the direction of the river from near Diamond Springs, the lowest point to which he traced it down to the plains, W. A. Goodyear expresses the opinion that it probably passed through the gap at Pilot Hill and thence to Folsom, where large accumulations of gravel occur.*

Any other course than by Pilot Hill is indeed out of the question on account of high bed-rock ridges. That it followed the windings of the canyon of the South fork where it cuts through these ridges is so improbable a proposition that it may be left out of the discussion. No remnants of gravels or volcanic flows, however insignificant, are found along this course to give probability to such a view. That the river continued from

* Auriferous Gravels, p. 504.

Diamond Springs in a northwesterly direction toward Pilot Hill is indeed proved by the small remaining deposit of gravel and rhyolitic tuff found at the low, broad gap of Granite hill in such a position that it must indicate the lowest point of the channel at this place. The town of Pilot Hill occupies a similar position in a broad gap, on each side of which hills of older rocks rise to a height of several hundred feet. Besides some Pleistocene angular gravel, there is found at this place a small remnant of another deposit with large, very well rounded bowlders, such as can be formed only by a stream of some magnitude. The course from here on is largely hypothetical, but it may be assumed as probable that the river continued in a westerly direction for some miles, joining the Neocene North fork coming down from the vicinity of Forest hill. From here on the two rivers, united, probably flowed in a southwesterly direction to the Neocene gravel masses exposed and mined near the plains between Rocklin and Folsom, at the Lee or Chabot drift mine. From this point the ancient river is hidden under the later accumulations of the plains. The Neocene surface in this vicinity appears to have formed a gently undulating country with little relief as compared with the lowest part of the Yuba river. This is explained by the occurrence of a large *massif* of easily eroded and crumbling granitic rock, over which the old river here made its way. That the gravels at the Lee mine are pre-volcanic cannot be absolutely asserted, but they are certainly of Neocene age.

If the gravel at the Lee mine represents the lowest point known of the Neocene river, it follows that it was here only about 100 feet higher in elevation than the present river in a corresponding position is now.

On the northern side of the sloping breccia table of "Bowlder ridge," extending from Auburn to Lincoln, there is another Neocene depression, the gravels of which have been drifted in places; but this cannot represent the lower course of the Neocene American, for a low granitic ridge separates it from the basin in which the continuation of the upper courses of this stream must be sought. On the other hand, the large accumulations of gravel near Folsom are distinctly post-volcanic and were accumulated by the river in early Pleistocene time. That the Neocene river followed the course of the present stream from Folsom up appears very improbable and is not supported by any geologic evidence.

Grades:

Lee mine to Pilot Hill, about 12 miles, 80 feet to the mile.

Pilot Hill to Granite hill, 11 miles, 32 feet to the mile.

Granite hill to Diamond Springs, 6 miles, 21 feet to the mile.

Diamond Springs to Newtown.—After a detailed examination of the gravel region in the vicinity of Placerville, Goodyear arrived at the con-

clusion that a stream of considerable magnitude once approximately followed the course of the present Webber creek from Diamond Springs to Newtown, and into which the complicated channels of the vicinity of Placerville emptied.* His observations did not extend beyond Newtown.

After a careful examination of the region I can only confirm his conclusion, with the addition that this stream without doubt represented the ancient South fork of the American river. It is very distinctly the deepest depression between the highlands of the Georgetown divide on the north and the high ridges on the south separating the Neocene American from the Neocene Cosumnes. The vicinity of Placerville, like the Forest hill divide, is characterized as a broad and flat Neocene depression, in which intervolcanic streams have cut a complicated series of channels. It should be noted that the oldest gravels of Placerville, as a rule, are not deep, and that in most of them occasional rhyolite bowlders are found. This would seem to indicate that during the earliest part of the gravel period the conditions were not as favorable here for the accumulation of river deposits as further northward.

About a mile west of Newtown the channel makes a curve, entering the volcanic ridge to the south of Webber creek. It then again turns northward, crossing the south fork of Webber creek about three-quarters of a mile to the northwest of Newtown.

Grades:

Diamond Springs to Webber hill, 2 miles, 71 feet to the mile.

Webber hill to Newtown, 7 miles, 69 feet to the mile.

Newtown to Pacific House.—After crossing the South fork of Webber creek the deep channel disappears under the volcanic capping of the ridge between the two forks of Webber creek, at a place formerly called Iowa City, but now generally known as Snows ranch. From this point it must continue under the eruptive rocks up to the Pacific house, on the stage road between Placerville and Lake Tahoe, where it crosses the present South fork of the American. The existence of a deep trough is unmistakably indicated by rising bed-rock toward the north and the south, by the pitch of the bed-rock wherever exposed along the margin of the volcanic area, and finally by the heavy flows of rhyolite and rhyolitic tuff with which the old depression, up to a certain level, was filled. A typical cross-section of this channel is shown in *K K*, with the probable position and depth of the channel indicated; it is, I believe, sufficiently clear to explain itself. Some extensive mining operations have been and are still carried on to find a deposit under the deep lava-

* Auriferous Gravels, p. 502.

flow north of the North fork of Webber creek, but that any large and important channel will ever be found on that side is very unlikely, except possibly at one point somewhat north of the section where a tributary from the north appears to join the principal river by way of Badger hill and Mooneys diggings (not indicated on the map).

The lower part at least of this large and important channel may not unlikely be found to pay for drifting; it can only be opened up by means of tunnels from near Snows ranch or from some places along the North fork of Webber creek. Inclines along the rim will probably suffer from a heavy influx of water.

At Pacific house the indications of an inlet are distinct, but I do not think that much gold was ever found in the adjoining gulches. Opposite that place, on a bench overlooking the South fork of the American river, a small isolated area of gravel has been washed away by the hydraulic process, and it is quite certain that the old channel crossed the river at this point. More indications of the same channel are found on the north side, a few miles eastward. Its course has not been traced further, but it appears probable that it will be found to cross the river again higher up, and that it headed up toward the Neocene volcanoes on the line between Eldorado and Alpine counties. The channel is not likely to be auriferous above the Pacific house.

A broad belt of Neocene highlands with lofty peaks and ridges occupied the space between the upper courses of the North and South forks of the American river, and on the Georgetown divide a spur extended from these highlands far toward the west.

Grade:

Newtown to Pacific house, 10 miles, 100 feet to the mile.

THE NORTH FORK.

From the Junction to Jones Hill.—The lower course of the North fork of the American river is almost completely destroyed by erosion; its probable course from the valley up to the junction has already been mentioned. Between the Lee mine and the Forest Hill divide there is only one remaining fragment, which, moreover, probably does not represent the very deepest part of the channel, namely, the small patch of mixed andesitic, rhyolitic, and metamorphic gravel found on top of the bluff at the junction of the present North and Middle forks, about three miles northwest of Auburn; the presence of rhyolite in this gravel is a strong proof that it came from the vicinity of Forest hill. This gravel is found in the center of a very broad, low depression bordered on the north by the Neocene highlands of Clipper Gap and on the south by the rising

divide separating the watershed of the Neocene North fork from that of the South fork. There are several small volcanic areas, sometimes underlain by gravel, two or three miles northwest of Auburn, near the railroad; but these are too high to have formed part of the principal channel. Between the small deposit mentioned and Jones hill no trace of the ancient river can be found.

Grades:

Lee mine to Auburn, about 14 miles, 86 feet to the mile.

Auburn to Jones hill, 9 miles, 63 feet to the mile.

Jones Hill to Bath.—A great many difficulties present themselves when an attempt is made to reconstruct the drainage southwest of Forest hill. Mr Browne has shown that a large antevolcanic channel enters the Forest hill divide at Bath and, making a large curve, passes by the Mayflower mine; thence to near Forest hill, where it comes near the margin of the volcanic cap, but turns again at the Dardanelles mine and runs in under the lava in a northwesterly direction.

Another channel enters under the volcanic ridge at Yankee Jim. Whether it connects with the Dardanelles channel is not known. The volcanic ridge continues down to Peckham hill, but only later intervolcanic channels appear to exist below it, which would seem to indicate that the older channel has in this vicinity been nearly entirely obliterated by those of a later period, if, indeed, it ever followed this direction. I have provisionally marked the older channel as following the ridge down to Peckham hill and joining another channel near Yankee Jim.

The so-called Ponds channel near Todds valley is at too high an elevation to have ever formed a part of the lowest antevolcanic channel, and should, I think, rather be considered as a bench gravel deposited after the filling up of the deepest depression.

The question of the continuation of the Mayflower and Dardanelles channels is very much complicated by the existence of a detached series of evidently antevolcanic gravel areas to the south of the Middle fork. I have provisionally connected them with a line running from Jones hill, with an elevation of 2,114 feet, by Floris, with an elevation of 2,530 feet, up to the channel which near Volcanoville emerges from the volcanic ridge south of the Middle fork.* The deposit at Floris is 140 feet lower than the main Dardanelles channel in a corresponding position. Any attempt to explain these apparent contradictions would lead too far into the realm of hypotheses.

It is certain, however, that a channel of some magnitude came down from the highlands of the Georgetown divide, crossed Otter creek at

* Several small Neocene tributaries came down toward this line from the Georgetown divide.

Kentucky flat, and continued from there under the lava cap to a place a short distance to the northeast of Volcanoville; at one intermediate point, Missouri gulch, it is exposed for a short distance.

Grades:

Jones hill (2,114 feet) to Floris (2,530 feet), 5½ miles, 76 feet to the mile.

Floris to Volcanoville, 3 miles, 112 feet to the mile.

Volcanoville to Missouri gulch, 2 miles, 114 feet to the mile.

Missouri gulch to Kentucky flat, 2 miles, 62 feet to the mile.

Jones hill to Peckham hill, 1¼ miles, 57 feet to the mile.

Peckham hill to Dardanelles, 5½ miles, 90 feet to the mile.

Dardanelles to Mayflower, 2½ miles, 52 feet to the mile.

Mayflower to Bath, 2½ miles, 40 feet to the mile.

The Iowa Hill Channel.—Difficulties also exist in connecting the Iowa hill channel with the rest of the drainage. I have assumed that a connection existed between Indiana hill and Iowa hill, and that the Iowa Hill channel ran southward and connected with the inlet at Yankee Jim. One of the principal objections to this view is the occurrence of a small gravel body at an intermediate point, Kings hill, which appears to be about 70 feet lower down than the lowest bed-rock at Yankee Jim. The Iowa hill or Morningstar channel, as it is also called, has been described in detail by Mr Hobson,* who concludes that the stream had a grade toward the north, and that coming from some point on the Forest Hill divide it was joined north of Iowa hill by a tributary from Indiana hill, after which it curved westward and flowed down toward the plains along the canyon excavated by the present stream. Mr Hobson's own figures on the maps and the profiles accompanying the paper do not seem to me to warrant this conclusion, as far as the grade is concerned. The bed-rock south of Iowa hill and at the hydraulic workings of the Morningstar has exactly the same elevation, according to the figures on Mr Hobson's map, as the starting point at the southern end of the covered channel at Wisconsin hill, a distance of between two and three miles. North of Iowa hill there is a sudden descent of some 50 or 60 feet, but the distance in which this descent is accomplished is only one-fifteenth part of the whole length of the channel; and it looks very much as if this depression were caused by a slight fault, especially as there are two or three of such disturbances shown on his profile in the Morningstar ground. An examination of Mr Hobson's profiles will inevitably lead to the conclusion that before the faulting, whether this took place by an uplift of the southern side or a downthrow of the northern, there was a

* Tenth Ann. Rep. State Mineralogist of California, p. 420.

slight southward slope from the Morningstar works to Wisconsin hill. Mr Hobson's arguments, based on the occurrence of serpentine bowlders in certain parts of the channel and on the relative elevation of the rhyolitic strata, are stronger. There are, however, such difficulties involved in carrying the principal channel in the direction advocated by Mr Hobson that I cannot adopt his view as the most probable.

Bath to Ralstons.—In discussing the upward continuation of the large and deep channel at Bath, which is the same as that of the Mayflower mine, Goodyear indicated several reasons why it was probable that it came down from the Long canyon country, the principal ones being the occurrence in it of granite bowlders and its capping of "white lava" (rhyolite). The vicinity of Long canyon was only examined in a cursory way by Goodyear. There is, indeed, at the Ralston mine, in the western part of the divide north of Long canyon, unmistakable evidence of an outlet of a large and important channel; there is, further, a remarkable and striking similarity between the accumulations of the Ralston channel with those of the Bath-Mayflower stream; there is, further, no other way open for the Ralston channel than in the direction of Bath, for higher bed-rock bars the way both to the south and to the north; hence I feel justified in concluding that a connection once existed between the two channels, which has since been eroded by the recent stream of the Middle fork.

Mr Browne is struck with the considerable extent to which the modern rivers on the Forest hill divide have avoided the older channels, leaving them buried under the volcanic flows on the top of the ridges.* To explain it he assumes that the ancient valley was filled with volcanic material only up to its widespread rims, but not to overflowing, and that the modern rivers started by preference along the marginal lines of the deposits. A study of the geologic map of the country north and south of the Forest hill divide will show that there is no good reason for such an assumption. On the contrary, the last flows almost completely flooded and buried the Neocene valley and its divides in this vicinity; the only points rising above them were the high hills to the west of the "Brimstone plains" and the Volcanoville hill to the southward. Only on the upper part of the Georgetown divide were there any continuous and important bed-rock ridges projecting above the general level of the flows.

The explanation of Mr Browne might well be applied to certain parts of the upper river courses, but I do not think it explains the positions of the present streams on the Forest hill divide. Slight inequalities in the surface of the andesitic flows probably determined first the directions.

*Tenth Ann. Rep. of State Mineralogist of California, p. 442.

Grade:

Bath to Ralston, 8 miles, 72 feet to the mile.

That Michigan Bluffs is not on the principal channel is also indicated by the grades, for from that place to Bath, a distance of three miles, the slope is 140 feet to the mile, while from Michigan Bluffs to Ralston, a distance of five miles, it is only 31 feet to the mile.

The Damascus and Last Chance Tributaries: General Character.—Mr Browne has described the Damascus or "white" channel. Its course above Damascus is eroded; it is practically continuous under the lava cap as far down as Gas hill; from there it is eroded for a long distance, but the characteristic deposits are again found at Michigan Bluffs. It is very different from the Bath channel, being almost entirely composed of quartz gravel, due to the fact of its flowing for a long distance over a soft clay-slate with a large amount of quartz veins. A short distance below Michigan Bluffs it must have joined the principal Middle fork.

Tributary to this channel was the Last Chance stream. Coming down from the high country to the northeast of Last Chance, it is preserved under the lava cap for some distance at Last Chance and again at Deadwood. It seems most probable that it joined the main stream some distance north of Michigan Bluffs. The relations of the lava and bed-rock at the two first-named places clearly indicate that this channel flowed in a very distinct depression or valley. Both at Last Chance and at Deadwood there is an older ante-volcanic besides several cement or inter-volcanic channels.

The important cement channel coming down from the vicinity of Secret canyon by way of Hogsback and Red point under the lava flow very likely followed an ante-volcanic valley; but of the deposits of the latter but little is left.

Grades:

Damascus to Michigan Bluffs, 8½ miles, 73 feet to the mile.

Deadwood to Last Chance, 5 miles, 136 feet to the mile.

From the Ralston Mine to Summit Valley.—The divide between Long canyon and the Middle fork of the American river is covered by very deep Neocene deposits and volcanic flows. High bed-rock exists to the north and to the south, forming the sides of a broad and deep depression, the center of which lies buried below the volcanic mass. This deep depression extends in a northeasterly direction up toward Summit valley a distance of about thirty-five miles, in which the deepest channel is only exposed at one point, at the place where the North fork of the American river cuts through it. This is the longest lava-covered stretch of channel in the territory here described. The parallelism with the

present Middle fork should be noted, as well as the bend in its lower course, which closely follows the curve of Long canyon.

The lower Course.—On the Long canyon divide—i. e., from the Ralston mine to the place called Big Flume on the map—the deposits in the channel preserve about the same characteristics. The general form of valley and depth of deposits are illustrated in section *H H* (plate 7).

It appears as if the channel in the Long canyon divide had in most places a broad, flat profile. On the bed-rock, as a rule, lies from twenty to forty feet of non-volcanic gravel, composed of quartz, quartzite and granite. Above this rests a series of alternating rhyolitic tuffs and gravels with rhyolitic pebbles, which ranges in depth from 150 feet at the western end of the ridge to 400 or 500 feet up toward Big Flume. In the western part of the divide the volcanic gravels are heavier, reaching 80 or 100 feet at the Ralston mine. Toward the east they grow thinner and the rhyolitic tuffs begin to predominate. Above the rhyolitic tuffs lie from 700 to 800 feet of andesitic breccia. The center of the channel evidently lies on the southern side of the ridge toward Long canyon, and an almost continuous fringe of gravels and tuffs are exposed along this line. At Blacksmith flat the bed-rock is propably not far above the deepest depression in the center of the channel, which here reaches its most southerly point. A smaller tributary at this place came in from the south by way of Corcorans diggings and Clydesdale, the bed-rock at the latter place, near the point between Long and Wallace canyons, being a little higher than that of Blacksmith flat. Again, at Russian ravine, one mile south of Big Flume, the bed-rock is probably nearly as low as that of the deepest channel.

Numerous attempts have been made on a small scale to mine these gravels. At Ralstons the upper gravels have been hydraulicked with satisfactory results; many small diggings are found along the rim on the southern side of the divide as far up as Big Flume, but nowhere, so far as I am aware, has any systematic and extensive work been undertaken in order to open up this magnificent channel by means of tunnels. It would seem very likely that some paying ground would be found along it: some risk must be taken, for it is of course impossible to predict whether a certain gravel channel will pay for drifting or not without a trial. That the channel exists and that it is of great dimensions is quite certain. Long canyon is said to have been rich in early days as far up as Russian ravine, while the Middle fork contained less gold.

Grades:

Ralston mine to Blacksmith flat (assuming that the bed-rock at the latter place is but little higher than in the deepest channel), 5 miles, 65 feet to the mile.

Blacksmith flat to Russian ravine (on similar assumptions), 7 miles, 93 feet to the mile.

The Duncan Peak Tributary.—A short distance from Big Flume, on the northern side of the ridge, there is a deep trough exposed, and known as Marshall's claim. It is, according to my measurements, 50 feet higher than the bed-rock in Russian ravine on the southern side, and it is filled to a depth of about 100 feet with gravel, of which a little has been hydraulicked. This place is evidently near the confluence of a tributary coming down with steep grade from the vicinity of the old Neocene mountain of Duncan peak. From Flat ravine, on the south side of Duncan peak, it runs down almost as a steep ravine to near the Gray Eagle tunnel; from here it must have connected across Duncan canyon with the main channel of the American river by way of Marshalls inlet. Abrams tunnel on Duncan canyon is probably in the same channel.

Grades:

Flat ravine to Gray Eagle tunnel, 2 miles, 350 feet to the mile.

Gray Eagle tunnel to Marshalls inlet, 6 miles, 200 feet to the mile.

The Canada Hill Tributary.—On the northern side of Duncan peak there exists another equally steep channel with thin angular gravel. Starting from Canada hill it runs down in a northeasterly direction to Sterrett's claim in Sailor canyon. From there its course is not determined beyond doubt, but it most probably curved around southeastward and joined the main channel near French meadows.

Grade:

Canada hill to Sterrett's claim, in 3 miles, 1,000 feet, or about 333 feet to the mile.

The upper Course.—From Big Flume the channel makes a curve toward the east and crosses the present Middle fork at French meadows, near Ralston dam. At this point the modern river is higher than the bottom of the old channel, but the distance along which there is no bed-rock exposed is short and there is no reason to believe that the deepest part of the channel is very far below the present river-bed.* Very little gravel is exposed from here up toward Summit valley; the rhyolitic flows have also changed character, containing more massive rhyolite and less of tuffs than before. They increase in depth, their thickness at French meadows being 600 feet, and south of Summit valley a maximum thickness of almost 1,000 feet is reached.

Whether the channel from Big Flume up toward Summit valley will

* Mr J. H. Hammond, in the Ninth Annual Rep. State Min. of California, plate 2, gives a cross-section from this vicinity where some prospecting has been done by tunnels and inclines. He, however, places the channel below the North fork, which certainly is incorrect.

pay for drifting is a very doubtful question. It is accessible only by long and costly tunnels from the North fork side or by inclines from the rims. There are but very few quartz mines along the upper course; the channel here enters the generally barren granitic area of the high Sierra.

Near Soda Springs the deep canyon of the North fork has cut through the channel, exposing on both sides the deep volcanic flows and the curve of the old valley. Section *L L* is laid across the valley a little south of this and shows sufficiently clearly the relations at this point. At Soda Springs the recent river is about 200 feet below the Neocene channel.

We are now near the headwaters of the ancient river; on all sides rise bed-rock ridges and peaks, prominent in Neocene as well as in the present time. North of the North fork the old channel begins to rise rapidly toward the summits. The valley opened up in a sort of amphitheater; one branch extended up toward mount Lincoln, another toward Soda Springs station. The principal valley extended up toward a point about a mile west of Summit station, and its continuation can indeed be traced a little further northward toward the high granitic counterforts of Castle peak. The Neocene river, broad and magnificent on the Forest hill divide, is here nothing more than a ravine.

Grades:

Russian ravine to French meadows, 6 miles, 100 feet to the mile.
French meadows to Soda Springs, 10 miles, 115 feet to the mile.
Soda Springs to Summit, 3 miles, 200 feet to the mile.

Discussion of Grades.

On plate 6 a first, and in many respects incomplete, attempt has been made to show in a comprehensive manner the more important facts about the present grade and directions of the ante-volcanic Neocene river beds.

Before endeavoring to draw any conclusions from the present condition of these river beds it should be pointed out that the Sierra Nevada is a very heterogeneous mass, composed of rocks of very diverse texture and hardness, which are apt to influence the grade of the rivers flowing over them. Sudden changes of grade are indeed not uncommon in the present rivers as well as in the Neocene channels. It follows from this that conclusions drawn from short distances of channel or based on isolated occurrences cannot be reliable.

An influence of direction on grade probably also exists, inasmuch as streams flowing parallel to the direction of the range would be expected to have a slighter grade than those breaking across the strike of the slates

or cross-belts of hard massive rocks. Such an influence no doubt exists, but it is certainly not very marked in the modern rivers. In the lower Sierra, in which the direction of the rivers for shorter distances only are parallel to the range, it cannot be stated to occur to any considerable extent; the principal forks have a fall of from 30 to 40 feet to the mile in whatever direction they run. In the upper Sierra the Rubicon river runs for fifteen miles near and parallel to the crest line, but the grade averages very high—about 150 feet to the mile.

The grades of the intervolcanic channels must be left out of consideration in endeavoring to ascertain whether the height of the range has been increased since Neocene times, for it has been shown that their erosive activity was similar to that of the present rivers, and that the changes from the conditions of the earlier Neocene to those of today took place or began to take place before the intervolcanic channel system was established. Referring to Mr Browne's diagram of the grades of the volcanic channels, it may be noticed that they in general show a strong grade in whatever direction they flowed.

Perhaps the first fact that attracts the attention when the grade sheet is studied is the remarkably steep grades prevalent. Down near the great valley, as well as high up in the mountains, grades of from 60 to 100 feet and above are noticed; these are certainly not the grades which would be expected in rivers depositing gravel in a country which, as shown by the topography, had been subjected to a long-continued erosion.

A further study will, however, show that while all of the transverse principal channels have a strong grade, most of the principal forks flowing in a direction about parallel to the trend of the range have a comparatively slight grade. The most striking instance of this is furnished by the Neocene South Yuba from Badger hill to You Bet. The sudden increase in grade from Waloupa to Dutch Flat (Thompson hill), where the river suddenly turns from a longitudinal to a transverse direction, illustrates this relation of grade and direction in an especially suggestive manner. A similar contrast is noticed at the junction of the North Bloomfield with the Grizzly Hill channel, and the course of the South fork of the American from Pilot hill to Diamond springs shows a strong tendency in the same direction. The grade of the longitudinal Forest City tributary is considerably less than that of the main river into which it empties, and the uppermost course of the Neocene Middle Yuba from Milton to Meadow lake in a longitudinal course shows a much lower grade than would be expected.

This generalization does not apply to all of the principal forks, however, for the grade of the important tributary extending from Damascus

to Michigan Bluffs is as heavy as that of the main river running in a nearly east-west direction; nor does it apply to the lesser tributaries. The one emptying into the upper North fork of the American river near Russian ravine has a very heavy grade, although running nearly parallel to the range. The same is true of the fragment of channel exposed south of Cisco. The Canada Hill-Sterrett channel offers an interesting instance of a steep Neocene gulch or creek running for some distance in a northeasterly direction.

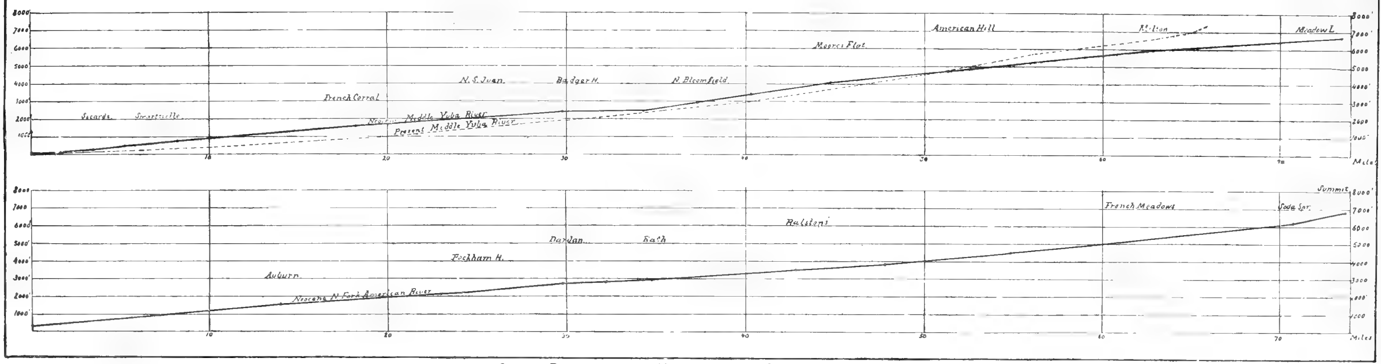
Another fact deserves notice. The North Bloomfield channel up to Moores Flat and the Dutch Flat-Lowell hill channel, in a corresponding position further south, show extremely heavy grades which scarcely can be sufficiently accounted for by harder rock-masses encountered. The North Bloomfield channel cuts with a heavy grade through the same siliceous slates over which the Blue Tent channel flows with a very slight grade. A mass of hard rock is met with at Dutch Flat, but between Dutch Flat and Lowell hill the slates are not particularly resistant.

Taking in consideration the fact that there is no essential difference in the character of deposits between the longitudinal and transverse rivers, the relation of grade and direction explained above is a strong argument in favor of a considerable increase in the slope of the Sierra since the time the ante-volcanic Neocene rivers flowed over its surface.

This uplift was probably gradual and extended over a long period, beginning at or shortly after the initiation of volcanic activity. The evidence from the region of the first summit in the territory here described appears to show that this disturbance ended about the time of the last great lava flows, and that while subsequent elevation might have taken place it has been of slight importance. It is necessary to add, however, that the region of the second summit has not yet been sufficiently examined to warrant the extension of the last statement to the whole range in this latitude.

If this increase in slope be attributed to a simple tilting of a rigid block, such as advocated by Professor Le Conte, if I understand him correctly, a reduction of the channels to fairly uniform grades is impossible; for if the range be supposed to be tilted downward so that the transverse channels with slighter grades become nearly level, many of the other transverse channels in which gravels have accumulated will still have a grade of 80 feet or more to the mile. The maximum amount of tilting to the mile cannot in this case have been more than the minimum grade of the transverse rivers, or from 60 to 70 feet to the mile. This would give a maximum increase of elevation of between 3,600 and 4,200 feet.

If, on the other hand, the increase in slope has been effected by means



GRADE PROFILES OF NEOCENE AND PRESENT RIVERS

of distributed faults of slight throw or equivalent plastic deformation, as held by Mr G. F. Becker,* the grades of the Neocene rivers might more easily be reduced to somewhat uniform figures by assuming that along distances showing exceptionally heavy grades a more intense faulting or deformation has taken place. The considerable and even steep grades of some longitudinal channels show, however, that even by this means the rivers cannot be reduced to gentle and uniform grades.

The vertical curve of the present Neocene channels would appear to offer a criterion by means of which it might be ascertained whether, in addition to the general uplift, the flank of the Sierra has been materially deformed. The grades of two principal forks of the old rivers which in general have a transverse direction have been plotted in plate 9, the distances being taken along the curves of the streams. In the same plate the vertical curve of one of the modern forks has been constructed in order to serve for comparison. The two curves in the upper part of the plate cannot be directly compared, and the difference in the ordinates does not directly indicate the amount of recent erosion, for the curve of the Neocene river is somewhat longer than that of the modern equivalent. It should first be noticed how regular is the curve of the recent river in spite of the fact that the country drained by it is only in the earliest stages of baseleveling. It is, strictly speaking, composed of two curves, the junction of which nearly coincides with the lower limit of glaciation. The existence of the upper curve must be referred to the ice-cap protecting the higher part of the mountains from active erosion during a large part of the Pleistocene.†

If the modern river curve shows such regularity it would be natural to expect that that of the Neocene river, which represents a more advanced stage of base-levelling, should be still more so. But the plotted curve of the Neocene Middle Yuba river does not correspond to the normal curve of erosion. Instead, it appears to be composed of two curves with the convex side upward. I think this convexity, which cannot be explained by differences in the resistance of the rock-masses over which the river flows, must be due to a deformation of the surface during the uplift of the Sierra. The most pronounced departure from the normal curve of erosion results from the present steep grades of the Neocene channels near the valley. This is marked in both the profiles given and must, I think, be regarded as indicating a subsidence of the portion adjoining the sediment-filled trough of the great valley relatively to the middle part of the range, or a rise of the latter relatively to the former. Another deformation would appear to have taken place in the

* Bull. Geol. Soc. Am., vol. 2, pp. 64 and 73; also idem, vol. 4, p. 89.

† See G. F. Becker: Bull. Geol. Soc. Am., vol. 2, p. 65.

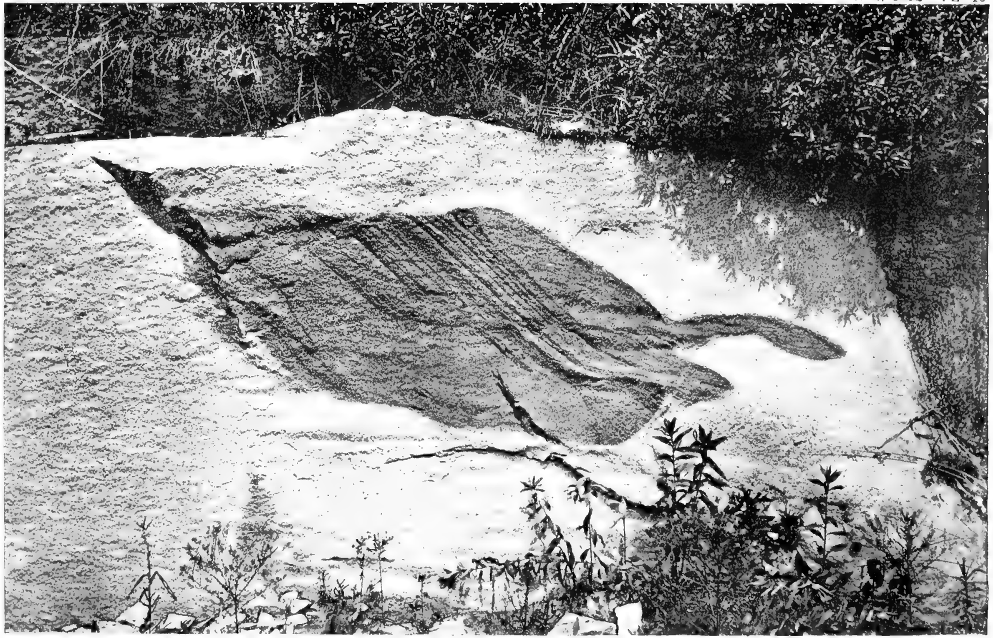
upper part of the first profile, while that of the second profile seems more like the normal curve of erosion.

It is evident that if, besides the deformation, a general increase in the slope has taken place the curves do not represent that deformation quite correctly, for a diminishing of the slope would affect the grades of the different sections differently according to their angle with the trend of the range. On recalculating the grades for a general decrease in the slope of 50 or 60 feet to the mile it is found, however, that the peculiar convex forms of the curves remain as before or even are slightly more accentuated.

Although the present steep grades of the old Neocene channel can thus be shown to have resulted to a considerable extent from elevation and deformation, it does not follow that the Neocene river system had very slight grades throughout. On the contrary, I believe that a careful study of the Neocene topography, as shown in valley slopes and cross-sections, which hardly can have been influenced by subsequent deformation and certainly have not been faulted to any notable extent, will lead to the conclusion that the Sierra Nevada, before the accumulation of gravels began, was a mountain range greatly worn down by erosion, but not reduced to a baselevel of erosion. It cannot even on the whole be regarded as a peneplain, above which isolated and more resistant hills projected; the declivities and irregularities of the old surface are too considerable for that, nor are the projecting hills invariably composed of the hardest rock-masses.

Conclusions.

The observations recorded in this paper appear to prove conclusively that the Sierra Nevada in Neocene times, in the watersheds of the Yuba and American rivers, formed a mountain range as distinct as that of today, and that its first summit in general coincided with the corresponding modern divide. They further appear to prove that the grades of the remaining Neocene gravel channels are to a certain extent determined by the directions in which they flowed in such a way as to strongly suggest that the slope of the Sierra Nevada has been considerably increased since the time when the Neocene ante-volcanic rivers flowed over its surface. It finally appears probable from a study of the grade curves of the remaining channels that the surface of the Sierra Nevada has been deformed during this uplift, and that the most noticeable deformation has been caused by a subsidence of the portion adjoining the great valley relatively to the middle part of the range.



GNEISS INCLUSION IN GRANITE.—WOODSTOCK, MARYLAND.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SOME MARYLAND GRANITES AND THEIR ORIGIN

BY CHARLES ROLLIN KEYES

(*Read before the Society December 30, 1892*)

CONTENTS

THE GRANITES.

Where found in Maryland.—The granitic rocks of Maryland have lately received special attention, both microscopically and in the field. They occupy small areas, a dozen or more in number, scattered through the eastern part of the central zone of the state, known as the Piedmont plateau. This belt is essentially a crystalline one, made up almost entirely of gneisses, which are broken through in numberless places by gabbros, pyroxenites and granites, and other closely related types of igneous rocks.

The different areas may be known from the chief places within their respective borders. They are Port Deposit, Texas, Windsor road, Relay,

Sykesville, Guilford, Garrett park, Woodstock, Ilchester, Ellicott City and Dorseys Run.

Their mineralogic Composition.—Microscopically the rocks under consideration are composed largely of quartz, feldspar and mica, with accessory plagioclase, microcline, magnetite, apatite, zircon, epidote, allanite, hornblende, sphene and often some other minerals.

Four Types represented.—Aside from their structural phases, the Maryland granites comprise four types: binary granite, granitite, hornblende granite and allanite-epidote granite. Each has been fully described in another place.

Origin of the Granites.

Two Theories advanced.—Regarding the origin of granites in general two leading theories have been advanced. One considers a granite as the last stage in the metamorphic change of mechanical sediments. With the other a granitic mass is regarded as the product of the gradual cooling of an acidic molten magma, and it is commonly supposed that the cooling takes place under pressure.

Recently great stress has been laid on the metamorphosing influences of orographic movements in disguising the original character of rocks, making eruptives more and more like sedimentary deposits, and clastic beds more and more like massives. But without entering into a discussion of the general subject, it is intended here to merely set forth some of the proofs that point to the eruptive origin of certain of the Maryland granites. That these particular rocks are really eruptive in character has been seriously questioned by some investigators, while by others the eruptive character is denied.

Localities favorable for Observations.—Perhaps the most favorable places for observing phenomena bearing upon the origin of certain of the Maryland granites are at Dorseys Run station, Woodstock, and Sykesville, all on the main line of the Baltimore and Ohio railroad a few miles west of the city of Baltimore.

At the first-named locality an excellent section has been exposed by a recent railway cutting. Here a dark-colored gneiss is found penetrated by a light-colored granitite. Huge blocks of contorted gneiss, often 10 to 20 feet across, and numerous smaller angular fragments are embedded in the massive granite. Some of the gneiss blocks are twisted and bent, to all appearances through movement when the granite was in a viscous state. Very light-colored granite dikes also cut in various directions. Chemical analyses show the dikes to be very much more acidic than either the gneiss or the massive granite.

At Woodstock similar irregular blocks of gneiss are abundant in the granite.

Inclusions and their Contacts.—From Sykesville many inclusions have been obtained in the granite a few rods below the railroad station, where a quarry has been opened. Recently great quantities of the rock have been removed for paving-blocks. During the progress of the work large numbers of inclusions of foreign rocks have been brought to light in the granite, furnishing indisputable proof of the eruptive origin of the granitic mass at this locality.

The inclusions found here consist of irregular fragments of all sizes and shapes, from minute pieces up to blocks of large size. Among the various fragments noted may be mentioned those which were evidently originally limestone, soapstone, pyroxenite, vein-quartz, hornblendic and biotitic gneisses. Both with the naked eye and in thin slices under the microscope characteristic contact phenomena are noticeable, similar in all respects to those observed where molten rocks and calcareous sediments or liquid lavas and certain crystallines have been brought together.

The inclusions derived from the limestone appear as thin yellow slabs from one to several centimeters in thickness and of various sizes. Four distinct zones are readily recognized, macroscopically, in the inclusions of this class: (1) The median portion is fine-grained and lemon-yellow in color. It is surrounded by (2) a narrow band usually 2 to 3 millimeters in thickness, white in color, and apparently composed chiefly of minute grains of quartz. Then comes (3) a very small, fine-grained, dark-colored shell of varying thickness, containing abundant small garnets up to one millimeter in diameter. In many cases this layer is so thin as to be scarcely noticeable. It shades off rather abruptly into (4) the typical granitite of the area.

Microscopically the four zones are even better differentiated:

The first of these zones is found to be a typical lime-silicate hornstone; the second is made up almost entirely of fine, allotriomorphic quartz, while the third belt is a fine-grained mixture of quartz and biotite, with small garnets.

Beside the limestone fragments there are abundant inclusions of soapstone, vein-quartz, biotitic and hornblendic gneiss. All of these rocks are well represented several miles to the eastward of Sykesville, where they dip to the west at a considerable angle. In the case of the two latter especially, the outside is usually changed considerably for a distance of about one centimeter. The interior of the gneiss pieces is practically unmetamorphosed. It is much lighter in color than the contact

border. The constituents have undergone much crushing and the feldspars are scarcely recognizable. The biotite is nearly all bleached, and chlorite is very abundant. There is also present secondary epidote and muscovite, and a few larger decomposing cubes of pyrite are scattered through the mass.

The margin of the gneiss blocks is dark colored and much finer in grain. No traces of pressure are noticeable, and apparently it has been completely recrystallized. Biotite is very abundant in small flakes, oriented in the direction of foliation. A little plagioclase and orthoclase occur, and also small quantities of pyrite.

Proofs of their eruptive Nature.—The proofs that the granites in question are eruptive in nature is deduced from several different and independent sources:

a. From field relations.
b. From inclusions.
c. From contact phenomena.
d. From microscopic examinations.

a. Their field Relations.—As stated elsewhere, the eastern half of the Piedmont region consists chiefly of gneisses broken through in numerous places by undoubted eruptives, such as gabbro, diorite and pyroxenite, until these rocks occupy fully one-half of the present exposed surface of the district.

Now, a careful tracing of the granites shows that they have cut indiscriminately across the igneous rocks mentioned as well as the gneiss, passing uninterruptedly from one petrographically distinct mass to another. In other words, the acidic types of crystallines to all appearances seem to be younger in age than the gabbros and the most basic rocks, as if they too had broken through all the other eruptives. Near some of the granitic masses, true granitic and felsitic dikes are clearly defined, which would ordinarily be regarded as apophyses of the main body were the rock regarded as an eruptive. Furthermore, at Dorseys Run station, for instance, large exposures show the granite forced between and spreading widely apart enormous layers of twisted and puckered gneiss; while at Woodstock huge blocks of gneiss are completely inclosed in the granite.

As already remarked, the line of contact between the granite and the contiguous rock is seldom determinable exactly, on account of profound superficial decay. Yet occasionally artificial excavations into the acid rock reveals clearly such contacts. A good example is that found at the new quarry opened about two miles northwest of Garrett park,

where the line is very sharply defined between the granite mass and the adjoining soapstone belt.

b. Their Inclusions.—Perhaps one of the most conclusive proofs of the eruptive nature of some of the Maryland granites is the occurrence in the masses of large numbers of inclusions—fragments of foreign rocks, both sedimentary and eruptive. These have all been described more or less at length in another place, to which reference may be made for fuller details. At Sykesville, where they occur so abundantly, the irregular angular fragments and blocks of all sizes are identical with rocks in the neighborhood.

In most of the cases observed, the interiors of the foreign pieces are scarcely altered at all, though the exterior forms more or less completely metamorphosed shells of varying thickness. The Woodstock and Dorseys Run granites show similar phenomena equally well or even better. In both instances, blocks of highly puckered gneiss are very prominent, and they all possess narrow marginal borders of dark, fine-grained, completely changed rock, which contrasts sharply with the light-colored surrounding granite.

Certain outcrops observed in the vicinity of Garrett park furnish good illustrations of the same kind, though here the granite has been squeezed considerably more than in the other case mentioned. At this place there is one exposure showing numbers of small lenticular masses of a black color which might easily be taken for inclusions but for their regularly rounded outlines. These are doubtless basic secretions which developed in the acid magma.

c. Their contact Phenomena.—For reasons elsewhere explained, the contacts between the granitic masses and the adjoining rocks are rarely seen to advantage. The investigation of the contact zones have therefore been carried on largely with the inclusions. This has been very satisfactory, on account of the variety of foreign rocks represented and the abundance of the fragments. In most of the fragments it is only the outside which is changed to the depth of from two to four centimeters or more, the interior still often preserving the rock in its original character, so that no doubt arises concerning its composition and structure previous to its embedding in the granite.

The contact zones are in all respects identical with the contact belts of other localities where acid eruptives have pushed up against the same kind of rocks.

Chemical analyses of the unaltered inclusions, the metamorphosed shells, and the surrounding granites show that the altered shells have an acidity intermediate between the inclusions and the granites.

These proofs of eruptive origin of the Maryland granites are quite similar to those which Barrois* has formulated from the granites of Rostrenen.

d. Microscopic Examinations.—Aside from the ordinary microscopic characters indicative of cooling from fusion, certain of the granites under consideration show some additional phenomena pointing to the same end. These are large grains, micropegmatitic intergrowths of quartz and feldspar, rounded through magnatic corrosion apparently and having the characteristic embayments so commonly associated with cases of this kind.

*Ann. de la Soc. géol. du Nord, t. xii, p. 106, 1885.

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EPIDOTE AS A PRIMARY COMPONENT OF ERUPTIVE ROCKS

BY CHARLES ROLLIN KEYES

(Read before the Society December 30, 1892)

CONTENTS

THE EPIDOTE-BEARING ROCKS.

Occurrence and eruptive Origin.—Very conclusive evidence has been found recently showing that certain granites of Maryland are eruptive in origin. The granitic masses occur in irregular bosses breaking through gneiss, gabbro and other crystalline rocks. In the central part of the state, at Dorseys Run station, Woodstock, Ilchester and Ellicott City, the acid eruptives are true granitites, granular aggregates, consisting essentially of quartz, feldspar and black mica, with considerable amounts of epidote and allanite as accessory constituents. These rocks vary considerably in color, from dark iron-gray to nearly white, according to the percentage of ferro-magnesian silicates they contain.

Microscopic Characteristics.—Under the microscope thin sections sometimes show that the incipient stages of dynamic metamorphism have set in. In other occurrences the granites show little or no signs of mechanical deformation. The occurrence of the two prominent accessory min-

erals in the Maryland acid rocks was first noted by Hobbs,* who had under consideration the porphyritic granites of the last two localities just mentioned. In the published notes particular attention is called to the isomorphous intergrowths of epidote and allanite. Since the appearance of the paper alluded to considerable additional material has been examined, both from the Ilchester and Ellicott City districts, besides three other places.

Comparison of Granites with Granitites.—In all their general characters the epidote-allanite bearing granites are essentially identical with the granitites of the region, except as a rule they are more basic and consequently much darker in color. The essential constituents show no noteworthy differences from the acid components of the typical granitites. In hand specimens a distinct greenish cast is often quite noticeable. Upon closer investigation the green specks are found to have frequently a reddish core. Microscopic examination in thin sections show that the two minerals are clear, usually idiomorphic or hypidiomorphic epidote, and reddish, intensely pleochroic allanite in parallel growths.

Allanite.

The mineralogic Associate of Epidote.—Before considering the epidote in detail a few words in regard to the allanite may not be out of place, as it is intimately associated and closely related chemically.

As a rock-forming Mineral reviewed.—As a rock-forming mineral, allanite has long been regarded as one of the rarer occurrences. Within the past few years, however, Iddings and Cross † have found this silicate of the rare earths widely distributed among acid eruptives, in some rocks forming an important accessory. Among the rocks in which the mineral under consideration was found may be mentioned gneiss, granite, quartz-porphyry, rhyolite, diorite, porphyrite, andesite, dacite and others. The localities in this country where allanite has been found to form a rock constituent are numerous, and are even widely separated geographically.

In Europe the apparent rarity of rock-forming allanite has made the observed occurrences somewhat noteworthy. There is a further interest centering around this mineral which is of no little importance from a historical point of view also. It is the fact that the presence of allanite in granite formed one of the chief arguments against the theory of the igneous origin of granite in the long-continued controversy that took place during the second quarter of the present century. The inability of this mineral to withstand a temperature higher than a dull-red heat

* Johns Hopkins University Circulars, no. 85, 1888, p. 70.

† Am. Jour. Sci., 3d ser., vol. xxx, 1885, p. 108.

without changing its physical character was evidenced as a strong proof against the igneous origin of granite. This objection was met by Scheerer * as early as 1842, in a paper entitled "Erste Fortsetzung der Untersuchungen über Gadolinit, Allanit, und damit verwandte Mineralien," read at Stockholm before the Society of Scandinavian Naturalists. Some years later the same writer † discussed an aqua-igneous theory of the origin of granite, and suggested that owing to the presence of water the magma may cool down considerably below the temperature necessary for solidification under the conditions of ordinary dry fusion, and thus allow minerals which cannot endure great heat to crystallize out before other constituents more difficult to fuse by the simple dry method. Both Élie de Beaumont and Daubrée and later others have confirmed this theory experimentally.

Since Scheerer's time a number of writers have noted the occurrence of allanite in various igneous rocks. Chief among these allusions may be mentioned those of Blomstrand,‡ von Fritsch,§ Vom Rath,‖ Liebisch,¶ Törnebohm,** Iddings and Cross,†† Michel-Levy and Lacroix,‡‡ Hobbs,§§ and Lacroix.‖‖

In Maryland, Hobbs appears to have been the first to call attention to the presence of allanite in the rock of the state. The specimens especially studied were from certain granites and porphyritic granite from the immediate vicinity of Ilchester. Since the announcement of these occurrences similar allanites and allanite-epidote intergrowths have been found at other places—at Dorseys Run station, and in less abundance at Woodstock, and on the Gunpowder river, northeast of Baltimore. Since the appearance of the first note on the allanite-epidote intergrowths from the porphyritic granite of the Ilchester district some doubts have been raised as to whether the exterior clear portions of the grains are not in reality the same mineral as the interior dark parts, but differing slightly chemically. For this reason the author ¶¶ just referred to reëxamined some of his earlier preparations and after the complete isolation of the dark central allanite had a chemical analysis made of some of the

* Poggendorff's Annalen der Phy. u. Chemie, lvi Band., 1842, p. 479.

† Bul. Soc géol. de France, 2d ser., tome iv, 1847, p. 468.

‡ Oefvers. af akad. Förhandl., no. 9, 1854, p. 296.

§ Zeitsch. d. d. geol. Ges., xii Band., 1860, p. 105.

‖ Zeitsch. d. d. geol. Ges., xvi Band., 1864, p. 255.

¶ Zeitsch. d. d. geol. Ges., xxix Band., 1877, p. 725.

** Geol. Fören i Stockholm Förh., vi Band., 1882, p. 185; also, Vega Exped., vol. iv, Stockholm, 1884, p. 115.

†† Am. Jour. Sci., 3d ser., vol. xxx, 1885, p. 108.

‡‡ Bul. Soc. min. de France, tome xi, 1888, p. 65.

§§ Johns Hopkins University Circulars, no. 65, 1888, p. 70; also, Am. Jour. Sci., 3d ser., vol. xxxviii, 1889, p. 223.

‖‖ Bul. Soc. min. de France, tome xii, 1889, p. 139.

¶¶ Am. Jour. Sci., 3d ser., vol. xxxviii, 1889, pp. 223–228.

epidote fragments, which show a very close correspondence with epidote of other localities, particularly Ludwig's specimen from the Untersulzbach. The following are the results obtained from the Maryland specimens by Dr Hillebrand, of the United States Geological Survey, and from the Tyrolean locality by Ludwig. The TiO_2 is probably due to the presence of sphene, which was not separated from the powder completely:

	Maryland.*	Untersulzbach.
SiO_2	37.63	37.83
Al_2O_3	18.40	22.63
TiO_2	3.78	
Fe_2O_3	15.29	15.02
FeO		0.93
MnO	0.31	
CaO	22.93	23.27
MgO	0.31	
P_2O_5	0.44	
H_2O	2.23	2.05
	101.32	101.73

EPIDOTE.

Its Abundance in Maryland Granite.—The epidote of the allanite-bearing granites of Maryland is frequently so abundant as to give a decided greenish cast to the color of the rock. Under a pocket lens the yellowish-green mineral is seen in small sharply bounded crystals or irregular grains, showing glistening surfaces of fracture and usually containing a central reddish interior, which already has been shown to be allanite.

Its microscopic Appearance—Under the microscope the epidote usually appears in sharply defined crystals or grains enveloping reddish grains of allanites, with which they are strictly isomorphous. Twins have not been observed, though the included mineral is often twinned. The sections are transparent, colorless or slightly yellowish, with imperfect cleavage. The pleochroism is quite marked, $\mathfrak{a}$ being colorless or very faint yellowish; $\mathfrak{b}$ light yellow, often tinged with green; $\mathfrak{c}$ greenish yellow. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Interference colors brilliant. The plane of the optic axes is perpendicular to the cleavage and direction of elongation. These characters, together with the chemical analysis given, correspond in all particulars with those of rock-making epidote.

Its Crystallography.—The simple crystals of epidote are usually quite small, and commonly have their crystallographic planes much better defined than in the other cases. The most frequently observed faces

* See also Bul. 64, U. S. Geol. Survey, p. 42.

are $OP \left\{001\right\}$, $\infty P \bar{\infty} \left\{100\right\}$, $2 P \bar{\infty} \left\{20\bar{1}\right\}$, $\infty P \breve{\infty} \left\{010\right\}$, and occasionally two small hemipyramids, probably $+ P \left\{\bar{1}11\right\}$ and $- P \left\{111\right\}$. The crystals, as well as many of the intergrowths with allanite, occur as a rule completely surrounded by biotite.

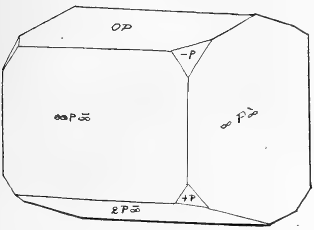

FIGURE 1.—*Microscopic Crystal of Epidote in Ellicott City (Maryland) Granite.*

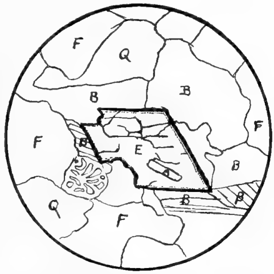

FIGURE 2.—*Epidote in Ellicott City Granite.*

An interesting occurrence of epidote is as an inclusion in sphene, along with an apatite and a greenish mineral having all the optical and physical characters of pleonaste. In other masses the sharply bounded

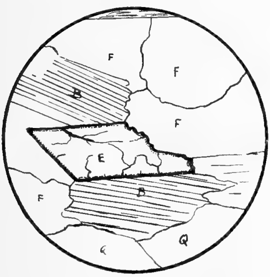

FIGURE 3.—*Epidote in Woodstock (Maryland) Granite.*

FIGURE 4.—*Epidote in Woodstock Granite.*

epidote comes in contact with unaltered feldspar, quartz and biotite grains and gives outlines to them.

Its Origin.—The origin of the epidote in the granite rocks under consideration is of great interest. Rock-making epidote has been regarded

almost universally as never forming a primary constituent of eruptives, or Archean masses, while as a characteristic ingredient it is abundantly developed in metamorphic gneisses, schists and phyllites. It is also a common product of both acid and basic rocks containing feldspar. The occurrence of epidote in acid eruptives has occasioned considerable discussion. Among the earlier references may be mentioned certain papers of Becher* and Blomstrand,† while the principal allusions to the subject during the past decade have been made by Törnebohm,‡ Geikie,§ Rosenbusch,|| Hobbs,¶ and Adams.**

The general consensus of opinion as derived from the literature referred to has been against the idea that the epidote was original in any of the cases mentioned. Hobbs,†† who was the first to study the Ilchester (Maryland) granite, was inclined to believe that the epidote was of metamorphic origin. Very recently Adams‡‡ has investigated some epidote-bearing granites from Alaska, in which the mineral alluded to is thought to result from the recrystallization of certain of the rock's constituents after the original solidification of the mass. The epidote is regarded as "having grown into the surrounding minerals by first sending out little arm-like extensions from its substance which subsequently met one another, in this way including some of the foreign minerals, which may or may not finally disappear" (page 349). Parallel growths of allanite and epidote are explained by the former being regarded as "a primary mineral around which the epidote would naturally crystallize, if any were developed in the rock, the two minerals being isomorphous" (page 350).

In his "Contributions a l'étude des gneiss à pyroxene et des roches à wernerite"§§ Lacroix has figured and described some interesting occurrences of isomorphous growths of epidote and allanite in the amphibolic gneiss of Geffren-en-Roscoff. They are considered analogous to Ilchester examples with which he has compared them. These growths are also reported from certain rocks of Finisterre, Norway, and Waldviertel, the epidote in all these instances being regarded as primary (page 353).

The association of certain of the allanites and epidotes in the granites of Maryland is so intimate that there can be but little doubt that both

* Ueber das Mineralworkomen in Granite von Striegan, u. z. w. (Boslau).

† Oefvers af. akad. Förhandl., no. 9, 1854, p. 296.

‡ Geol. För. i Stockholm Förhandl., vi, 1882, p. 245.

§ Quar. Jour. Geol. Soc. vol. xxxix, p. 314.

|| Mik. Phys., i Band, 1885, p. 498.

¶ Johns Hopkins University Circulars, no. 65, 1888, p. 70; also Am. Jour. Sci., vol. xxxviii, 1889, pp. 223–228.

** Canadian Record Science, 1891, pp. 344–358.

†† Loc. cit.

‡‡ Loc. cit.

§§ Bul. Soc. min. de France, tome xii, 1889, p. 139.

minerals were formed under the same physical conditions, so that any remarks upon the origin of the one would apply equally as well to the other. In attempting to determine whether or not these minerals are of primary or secondary origin in granitic rocks, the evidence must necessarily be based in great measure upon the observed association with the other minerals. Allanite, as has already been stated, is comparatively easily fusible, and on this account it long has been quoted as one of the proofs against the igneous origin of granite; but its occurrence in such rocks as unaltered porphyrite, quartz-porphyry, dacite, andesite, and rhyolite masses whose eruptive nature, as shown by Iddings and Cross,* is not to be questioned, shows conclusively that this mineral actually does form in a molten magma.

Furthermore, the epidote occurs included in well-defined crystals of sphene whose primary character cannot be doubted; besides, it is not uncommon to find sharply defined crystals completely mantled by biotite, along with similar inclusions of zircon, apatite and magnetite. There is further evidence pointing toward the original character of the epidote in the occurrence of broken crystals of allanite-epidote intergrowths, into the open fractures of which biotite has formed. To all appearances these fractures are protoclastic in nature. Finally, crystals of epidote or isomorphous growths of epidote and allanite, with the crystallographic planes well defined, are found giving shape to the unaltered feldspars, quartz and mica.

Summary.

In summing up the facts already presented it would appear that the evidence of the primary occurrence of epidote in the eruptive rocks is essentially the same as that for allanite. Attention has been called to the fact that allanite, though easily fusible, is now known to be widely distributed, and is often an abundant accessory in such rocks as dacite, porphyrite, diorite, quartz-porphyry, rhyolite and others the igneous nature of which cannot be questioned. All physical obstacles as to its primary origin are manifestly removed. The evidence, therefore, in any particular case that this mineral is either primary or secondary must be derived largely from the study of its associations with other minerals.

Now the epidote of certain of the Maryland granites is found in isomorphous growths with allanite, as well as in separate well-defined crystals. Both occurrences are found in sharply bounded individuals, and the following remarks apply to the intergrowths and single crystals

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* Am. Jour. Sci. 3d ser., vol. xxx, 1889, p. 109.

alike. That these must be original constituents, and not secondary products, is indicated by—

1. Its presence in perfectly fresh rocks or rock but slightly altered by orographic movements.

2. Its inclusion in sphene, one of the earliest components to crystallize out from the molten magma.

3. Its occurrence with sharply defined crystallographic faces, completely mantled by clear, unaltered biotite or feldspar, and giving shape to some of the essential constituents of the granite.

4. Its presentation in long crystals, broken and bent, and the interstices and parted cracks filled with biotite, and often continuous with, and optically oriented the same as, the surrounding black-mica crystals, whose shape is partially given by the epidote. These fractures appear without doubt to be protoclastic in origin.

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RELATIONS OF THE LAURENTIAN AND HURONIAN ROCKS NORTH OF LAKE HURON*

BY ALFRED E. BARLOW

(Read before the Society December 30, 1892)

CONTENTS

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INTRODUCTION.

In this paper, which is a revision and extension of one published in the American Geologist of July, 1890, the writer proposes to bring forward some observations on the nature of the contact between the Huronian rocks of Lake Huron, described by Logan and Murray, and the Laurentian gneisses, which it is thought have an important bearing on the question of the origin and relative age of the latter.

THE HURONIAN ROCKS.

The rocks of the Huronian area to the north of Lake Huron are made up of a series of quartzites, graywackes, slate conglomerates, clay slates hydromica, chloritic, and hornblendic schists, greenstones and some bands of cherty limestones or dolomites. Frequently these rocks show a pyroclastic origin, and tuffs and breccias are very commonly met with. The majority of the clay slates have the appearance of being very little altered, except in contact with the greenstone and other igneous rocks, and present in great part the same appearance as when hardened from the original soft sediments. The quartzites, graywackes and slate con-

glomerates have all been altered more or less by the secondary enlargement of the component grains and the deposition of interstitial silica, and one can frequently obtain specimens showing a perfect gradation from the loose, friable sandstone to the almost completely vitrified quartzite, there being every possible phase between these two extremes. In the vicinity of the gneiss and granite both the quartzite and graywacke are altered into mica schists.

THE LAURENTIAN ROCKS.

The Laurentian to the north of Lake Huron is chiefly represented by gneiss which differs from granite only in being foliated. Frequently this foliation is quite distinct, though sometimes it is obscure and occasionally it cannot be detected at all, the rock being then indistinguishable from ordinary irruptive granite. Intimately associated with the gneiss are certain true granites and syenites, non-foliated and varying in texture from coarse to fine-grained. Although in many cases there is the clearest evidence that these granites cut the gneiss, yet for the following reasons both may be considered to have had a common genesis:

1. The presence of streaks and lenticular patches of darker-colored material in the midst of these non-foliated areas, all of which have a more or less constant direction.

2. The frequent absence of any sharp line of division between the gneiss and granite, the one passing into the other by insensible gradations.

3. The occurrence of dikes and veins of pegmatite cutting both the gneiss and one another clearly belonging to the same period, although the fact of one cutting the other would seem to indicate a lapse of time, which in this case was doubtless of small import.

4. Their close resemblance in composition, appearance and behavior.

These masses of granite may therefore be regarded as non-foliated areas of gneiss, representing simply certain irruptions from the same fluid magma from which the gneiss itself has solidified, and although a sufficient time has elapsed to allow of the more or less complete consolidation of the gneiss, yet they represent the same age in geologic time. The first-formed crust was necessarily thin and weak, so it is not surprising that the basement complex exhibits such frequent evidence of the upwellings from beneath of the fluid magma. The non-foliated character of many of these masses may have been due to their very gradual intrusion and the absence of pressure during the process.

General Course of the Contact on Lake Huron.

On Lake Huron the contact between the Laurentian and Huronian comes out on Killarney bay, a mile and a half north of Killarney post

office (Shiboananing). Thence, crossing Lamorandiere bay, it reaches George lake at the southwestern end. It then appears to pass through George lake and, following its inlet from Ka-ka-kis lake, crosses the latter about the center, cutting the western boundary of the township of Carlyle about five miles north of Collins inlet. It then strikes across the country for about four miles, reaching Brush Camp lake two hundred and fifty yards north of the Crooked Lake narrows. Crossing two points which jut out into Brush Camp lake, it intersects the neck of land between this and Three-mile lake, reaching the latter at its southeastern end. Continuing through Three-mile lake for about two miles, it crosses the eastern boundary of the township of Goschen three miles and a half south of Lake Panache. Throughout this distance of twenty miles the line of junction runs with gently sweeping curves in a general direction of N. 60° E. The La Cloche range of mountains ends somewhat abruptly at Brush Camp lake, for Northeast peak, the highest in the range (1,762 feet above the sea), is but two miles east of this lake. These hills are composed of Huronian white quartzite, and are here interrupted by the gneiss, which occupies comparatively lower ground.

The Lake Huron Localities in Detail.

KILLARNEY VILLAGE.

Huronian and Laurentian Rocks found there described.—Dr Robert Bell, in his report* on the geology of the neighborhood of the village of Killarney (Shiboananing), says:

"The village itself stands upon red syenitic granite, which, except at the sides, has a massive homogeneous structure, but in a few instances a single reddish or yellowish green shaly streak an inch or two in thickness was observed, running in a northeasterly direction. Toward each side the grain of the rock begins to assume a sort of parallelism or a gneissoid structure. The granite is flanked by a stratified rock of reddish-gray color, consisting of a fine-grained crystalline mixture of feldspar and quartz."

Both rocks have approximately the same northeasterly strike, but while the Huronian beds are about vertical, the granitoid gneiss dips southeast at an angle of 50°. Dr Bell refers this granitoid gneiss to the Huronian rather than the Laurentian, although he gives no reason for so doing. The coincidence in direction of the streaks in the midst of the granite itself, the absence of any sharp line of division, as well as the more perfect development of the foliation near the junction of the Huronian strata, are characteristic features of obscure or non-foliated gneissic areas.

* Report Geol. Survey Canada, 1876-'77.

Extent of the Huronian.—The dark feldspathic sandstones and shales of the Huronian form a triangular patch in the northern part of the township of Rutherford, and are followed to the north by the vitreous quartzite of the La Cloche mountains. The base of this triangle on Killarney bay is about a mile in length, while the apex is at George lake, where these rocks thin out, being replaced to the northeast by the snow-white quartzite in contact with the gneiss. Mr H. G. Skill, of McGill University, my assistant for a time, tells me there is abundant evidence of the irruption of the granitoid gneiss in the alteration and disturbance of the sedimentary strata, while a band or zone of graywacke in contact with the gneiss frequently shows feldspathic matter intruded parallel to the strike.

BEAVER, FOX AND BALSAM LAKES—THE ROCKS AND THEIR CONTACTS.

The shores of Beaver, Fox and Balsam lakes on the route from Lake Panache to Collins inlet, it was observed, are occupied by a dark greenish-gray feldspathic sandstone or graywacke which occasionally contains pebbles of a coarse, red granite. The strike of this rock is in general nearly east and west, and the dip southerly at a high angle, but as the rock is often massive this cannot always be determined with certainty. In the northeastern part of Balsam lake a small area of granitoid gneiss is exposed, but the immediate contact with the enclosing graywacke was not seen, owing to an intervening marsh.

CHARACTER, CONTACT AND RELATION OF THE ROCKS OF THREE-MILE LAKE.

The Huronian rocks continue through Balsam lake and on to Three-mile lake with a strike of S. 75° E. (dip S. 15° W. at a high angle), but upon entering the latter body of water they quickly curve round first to southeast, then south, and finally pinch out near their contact with the gneiss, giving place at this point to the white quartzite of the La Cloche mountains, the latter rock continuing in juxtaposition with the gneiss as far as George lake. The graywacke in the northern part of Three-mile lake shows abundant signs of disturbance and pressure and is altered into a dark-gray mica schist, with uneven or lumpy cleavage surfaces. This rock is probably the equivalent of the graywacke exposed in the northern part of the township of Rutherford, having been cut out through the intervening space by the irruption of the gneiss. The contact between the two rocks on Three-mile lake is seen on the eastern shore nearly two miles south of the inlet from Balsam lake, the gneiss occupying the southeastern shore and off-lying islands, while the quartzite forms the mainland to the northwest. The gneiss is coarsely crystalline, dark flesh-red in color, porphyritic; large feldspar crystals

being seen embedded in a matrix composed of feldspar, quartz, and mica. Feldspar is by far the most abundant constituent, and the foliation, which is quite distinct, consists chiefly of a parallel arrangement of the feldspar crystals. Embedded in the gneiss are patches and strips of highly altered quartzite, plainly referable to the Huronian quartzite in the immediate vicinity and corresponding in strike with the foliation of the enclosing rock.

TRANSITIONAL ROCK-MASSES BETWEEN THREE-MILE AND BRUSH CAMP LAKES.

To the northeast of Three-mile lake, and also between this and Brush Camp lake, there appears the interesting phenomenon of a sort of transition from one formation to the other. At these places a band of gneissic quartzite occurs which may be due to the fusion of the two rocks *in situ* and the absorption or passage of the components of one rock-mass into the other. Both rocks incline to the southeast, the quartzite dipping into or under the gneiss.

THE CONTACT ON BRUSH CAMP LAKE.

On Brush Camp lake the immediate contact was seen at three places, the two rocks in these cases holding the same position as on Three mile lake, but the line of division is sharp and distinct. At one point on the north shore a boss of coarse red gneiss was seen protruding through and disturbing the quartzite, the strike of the latter curving round so as to conform with its outline.

THE QUARTZITE AND GNEISS OF CROOKED AND JOHNNY LAKES.

On Crooked lake it was observed that four irregularly-shaped patches of quartzite had been apparently caught up in the gneiss, the contrast in color between the two being very marked. The largest one of these on the west shore was triangular in outline, measuring about a quarter of a mile in length. A mass of the same white quartzite was also noticed embedded in the gneiss on a small island in Johnny lake, nearly one mile and a half from the line of junction.

GOSCHEN TOWNSHIP AND LAKE PANACHE.

Direction and Extent of the Contact.—From the eastern boundary of the township of Goschen the line of division turns in the direction of N. 20° E. for about four miles, passing Lake Panache about a mile to the east.

Quartzite and its microscopic Examination.—The shores and islands of the eastern portion of Lake Panache are occupied by a granular quartzite of varying shades of gray. Mica in the form of minute disseminated

scales and also feldspar are usually present in small quantities. A specimen of this rock was obtained from the north shore of Archie bay, four miles from the contact, which might be regarded as a typical specimen of the less altered rock. A thin slice of this was examined under the microscope by Dr A. C. Lawson, who says:

"A fine-grained, light yellowish-gray quartzite, rust-stained in places; under the microscope it is seen to be a crushed quartz sandstone; a cataclastic condition is seen to have been induced upon the original epiclastic grains of quartz; wavy extinction is common. There is a rude parallel arrangement of the quartz grains in long areas, and between the constituent grains is a fine cement which is largely made up of a felt-work of muscovite. In some portions of the slide this felt-work of muscovite is mixed with clastic grains of quartz and forms a base in which the larger clastic grains are embedded. Besides quartz, there is present a notable proportion of fragments of feldspar."

Disturbance causes Change of Strike.—About three miles from the contact with the gneiss these Huronian quartzites show signs of great disturbance, and the strike which has hitherto been nearly east and west turns abruptly to the southeast, this change being still further continued till the strata have assumed a southwesterly strike, thus corresponding with the line of outcrop of the gneiss in this direction. A little to the north of the eastern end of Lake Panache and emptying into it is Gabodin lake, about two miles in length. At the western end or outlet of this lake micaceous quartzites were noticed with a strike of N. 75° E., which curves around quickly, for on the islands in the eastern part of the lake quartzose mica schists were seen striking N. 15° E., these rocks being thus conformable with the line of outcrop of the gneiss in its northerly continuation.

Alteration in Character of Rocks accompanies Change of Strike.—This rapid change in the strike of the quartzites is accompanied by a very marked alteration in the character of the rocks themselves. The granular quartzites and sandstones which have previously shown no further signs of alteration than a hardening consequent on the addition of secondary silica are now metamorphosed into very typical quartzose mica schists. The change is gradual but marked and extends to a distance of three miles from the line of junction.

Microscopic Examination of altered Quartzite.—Dr Lawson examined two slides of this quartzite under the microscope. Of the first he says:

"A light gray, fine-textured, somewhat micaceous quartzite, with occasional 'sheen surfaces' along shear planes. Under the microscope the rock is seen to be an aggregate of subangular or rounded quartz grains with a subordinate proportion of feldspar grains, most of the latter being quite fresh and showing the multiple twinning of plagioclase. Some of this plagioclase is clearly in original clastic grains, but some appears to be of secondary interstitial growth. Scattered throughout the

slide are numerous scales of brown biotite and a less proportion of muscovite. Most of these mica scales have a parallel arrangement, but some are seen to have been developed in the curved lines or areas between the original clastic grains. Some of the quartz grains show evidence of pressure in the optical tension which they manifest under crossed nicols. Inclusions are not abundant in the quartz."

Of the second slide he says:

"A silvery micaceous, very quartzose schist, somewhat rusted, and with strongly micaceous sheen surfaces. Under the microscope the rock is seen to be composed essentially of quartz and muscovite. There is a well-marked parallelism in the arrangement of the muscovite, and the quartz shows distinct cataclastic structure, wavy extinction arrangement in parallel areas and other crush phenomena; evidently an altered sandstone."

Bedding Planes of and intrusive Masses in the Huronian mica Schists.—The planes of bedding of the Huronian mica schists are parallel to the lamination of the gneiss. Both rocks have a strike N. 25° E. and a dip S. 55° E. of 75°, the mica schists dipping into or under the gneiss. Penetrating the schists are lenticular sheets and patches of gneissic material similar in character and composition to the great mass of the gneiss in the immediate vicinity, to which they may often be continuously and directly traced. These intrusions of gneiss have disposed themselves usually in a direction parallel to the bedding of the schists, thus showing the coincidence of the lines of least resistance with the lamination of the schists. The intrusive nature of these gneissic patches and sheets is quite evident from even a cursory examination of the relations of the two rocks *in situ*, for the foliation of the gneiss composing these intrusions is parallel to the walls of the fissures even when these fissures cross the strike of the schists. This also seems to demonstrate that gneissic lamination is caused by the flow of the rock under differential pressures. Angular fragments of the Huronian mica schists are included in the gneiss, the foliation of the latter conforming roughly with the irregular outlines of the fragments, the flow structure thus produced being always very marked.

Microscopic Examination of Quartzite and granitoid Gneiss.—There was obtained from this locality a hand specimen, which, before being sliced, showed a dark greenish-gray fine-grained quartzite, with two small bands of granitoid gneiss irruptive through it. Dr Lawson thus describes it:

"Under the microscope the quartzite is a typical epiclastic rock, presenting no strong evidence of deformation by pressure. It consists of a heterogeneous aggregate of clastic grains of quartz and feldspar, much of the latter being plagioclase. In sections the shape of these grains is rounded, subangular, or sometimes angular. The larger grains are embedded in a base composed of much smaller grains of the same materials, but intimately mixed with a green chloritic substance, which gives its color to the rock. The section crosses the contact of the granite stringer and

the quartzite. The contact between the two is sharp, but ragged, and portions of the clastic rock are seen to have been incorporated in the granite. The granite itself is a coarse, angular aggregate of orthoclase and quartz, with extremely little of the ferro-magnesian constituent. There is a certain amount of finer base in the granite, of which it is difficult to say whether it is simply a later and more rapid consolidation of the magma about the larger constituents or whether it is a portion of the clastic rock, which has been incorporated without fusion in the granite."

Other Localities.

WAVY LAKE.

Direction of the Contact.—The contact was next seen on the western shore of Wavy lake about six miles in a direction N. 16° E. from the place where it was examined east of Lake Panache.

Character and Relation of the Gneiss and Quartzite.—In the southern part of Wavy lake the gneissic foliation has a northeasterly trend, which, in coming north, gradually curves around to an almost easterly direction. In the northern portion of the lake the strike bends around very abruptly from a northeast to a southeast direction, and the change is further continued till in the eastern part of the lake the lamination of these two areas of gneiss converges in a common strike of N. 70° E. A funnel-shaped trough is thus formed in the western part of the lake, which is occupied by a tongue of highly inclined Huronian quartzites. At the southern edge of this trough the quartzites abut on the gneiss as on an irruptive mass, the strike of the former being N. 65° W.; dip, S. 25° W. $\angle$50°, while the foliation of the gneiss is N. E.; dip, S. E. $\angle$75°. At the northern edge of the trough the stratification of the quartzites corresponds in direction with the lamination of the gneiss. Both rocks strike S. 38° E., although their declination is in opposite directions; the quartzites dipping S. 52° W. $\angle$80°, while the gneiss dips N. 52° E. $\angle$80°. The quartzites near the line of junction on Wavy lake are not so highly altered as on Lake Panache, yet the proportion of mica in these rocks is seen to increase as the gneiss is approached.

Microscopic Examination of the Gneiss.—Dr Lawson thus speaks of a thin slice of this gneiss which was examined by him:

"A reddish, highly feldspathic granite, with occasional shear planes traversing it. Under the microscope the rock is a granular aggregate of orthoclase, quartz, plagioclase and biotite, in which crush phenomena are to a limited extent apparent. The orthoclase is very much kaolinized in its central portion, but quite fresh in the peripheral zone. The plagioclase is, as a rule, fresh. The biotite is very sparingly represented and is almost entirely altered to chlorite. There is present also a little iron oxide. The effect of secondary pressure is seen in the occasional dislocation of the plagioclase and in cataclastic structure which has, to a limited extent, been developed in portions of the section."

Cleavage Planes and embedded Quartzite.—Where the quartzites abut on the gneiss on Wavy lake a set of cleavage planes is developed parallel to the line of contact. At the eastern end of the lake, where the foliation of the northern and southern areas of gneiss converge in a common strike, angular fragments of various sizes of the Huronian micaceous quartzites were noticed embedded in the gneiss, the foliation of the latter flowing around the irregular outline of these fragments.

CHIEFS LAKE.

The Contact.—From Wavy lake the line of demarkation curves around very quickly from northwest to northeast, and was next seen on the north shore of Chiefs lake, on the south line of the township of Broder (Salter's base line), three and a half miles east of Long lake. Throughout this distance of nearly six miles the general strike is northeast.

The Rocks.—The late Mr Alexander Murray, who made an examination of the rocks exposed on Salter's base line, simply describes the boundary here as a junction between "red gneiss" and "greenish mica slate."

BRODER TOWNSHIP.

Direction and Extent of the Contact.—The line from this point strikes due north into the township of Broder for about a mile, when it bends around to the northeast for half a mile, and then to N. 78° E., which general strike it maintains till the eastern line of Broder is reached. Where this last abrupt change in the line of junction takes place the Huronian rocks, with a strike of N. 75° E. and dip S. 15° E., abut on the gneiss, whose lamination has a direction of N. 40° E. and dip S. 50° E. <68°. Throughout the remaining part of the township of Broder, however, the micaceous slates and quartzites have approximately the same strike and dip as the gneiss. The gneiss is always superimposed on the sedimentary strata and both rocks dip in a southerly direction at angles varying from 65° to 70°.

Microscopic Examination of Huronian Schist.—A specimen af the Huronian schist was obtained on the line between lots 4 and 5, concession III, three hundred and fifty yards north of the contact with the gneiss. Dr Lawson says of this:

"A gray, moderately fine-textured schist, spotted with scales of brown mica and having uneven or lumpy cleavage surfaces with marked silvery gloss. Under the microscope the clastic character of the rock is apparent, it being composed of grains of quartz and feldspar chiefly. Throughout this clastic aggregate there have been developed numerous plates of brown mica and some of muscovite, nearly all in parallel position. Scattered thoughout the slide are nests of separated or closely aggregated grains of a light-yellow pleochroic mineral, probably epidote.

The separate grains of epidote in each nest have for the most part all a common orientation and extinguish together. None present crystallographic boundaries nor distinct cleavages."

Microscopic Examination of the Gneiss.—A specimen of the gneiss obtained from the contact on the line between lots 4 and 5, concession III, showed its contact with the Huronian schist. Of this Dr Lawson says:

"A pinkish to yellowish gray medium-textured biotite granitoid gneiss, with a portion of very fine-textured greenish gray schist partly adhering to and partly enclosed in the granite on one side of the specimen. The thin section examined is across the contact of the granite gneiss and the schist. In the section the two rocks are very distinct, and the contact, while fairly sharp, shows portions of the schists included within the granite. The granite is a granular aggregate of orthoclase, microcline, plagioclase, quartz, biotite and muscovite. * * * In the structure of the rock there are some slight evidences of pressure seen in the occasional dislocation of a crystal of plagioclase, but there is neither shearing nor cataclastic structure. The schist in contact with this granite is profoundly sheared, and it only requires an inspection of the slide to see that the shearing was effected before the magma from which the granite has crystallized was brought in contact with the schist. The schist is composed essentially of quartz and muscovite, and these minerals are arranged in parallel thinly lenticular areas which wedge into one another. The optical tension of the quartz lenses is very constant. The cataclastic structure of the quartz is pronounced. The general aspect of the schist is that of a streaky rhyolite."

Character of the Rocks near the Line of Contact.—Near the line of junction the silicious slates and quartzites become highly schistose and show signs of having been subjected to great pressure. Angular pieces of the schistose rocks are included in the gneiss, especially near the curve in the line of junction, while intrusions of gneiss were seen at several places penetrating the stratified rocks. In one instance a lenticular mass of distinctly foliated micaceous gneiss was seen intruded through the schists parallel to their bedding at a distance of three hundred yards from the line of contact. Besides these gneissic intrusions there are irregularly shaped fissures running transversely to the strike of the schists and filled with coarsely crystalline feldspar and quartz. In the larger portions of these veins the feldspar and quartz are present in about equal proportion, but where they begin to thin out quartz seems to be the main and in some cases the only constituent. These pegmatitic apophyses are evidently portions of the adjacent gneiss which have been injected through the schists and crystallized in the presence of heated vapors. A large pegmatite vein of this sort was noticed on the line between Broder and Dell extending across the strike of the schists for a distance of half a mile from their contact with the gneiss.

DELL TOWNSHIP, DAISY AND BABY LAKES AND LAKE ALICE.

Direction and Extent of the Contact.—The contact runs in general about northeast through the township of Dell, striking Daisy lake near the line between lots 6 and 7, in concession I, of the township of Neelon. Continuing through Daisy lake to its northeastern end, the line crosses through Baby lake and the northern end of Lake Alice.

Microscopic Examination of foliated Gneiss.—The Huronian throughout this distance is represented chiefly by a light yellowish feldspathic quartzite. As the gneiss is approached this quartzite shows abundant signs of alteration and disturbance. The immediate contact shows an intermixture of a dark green chlorite schist, which probably belongs to the Huronian, and a dark red well-foliated gneiss. Mr W. F. Ferrier, lithologist to the Canadian Geological Survey, who examined a thin section of this rock, says:

"Shows an intermixture of a granitic rock with a chlorite schist. In the granitic portion the quartz and feldspars are broken up into a fine mosaic, through which occasional larger grains are distributed. The quartz fills in the interstitial space between the larger fragments of feldspar. Plagioclase is present, but orthoclase predominates. A number of curious large crystals occur, too decomposed to admit of positive identification. The central portion of these crystals is made up of serpentinous material, and from the form of some of them the original material was probably hornblende. A much-decomposed pyroxene is also present. The schistose portion of this slide is exceedingly decomposed." * * *

Daisy Lake Rocks.—The northern shore of Daisy lake is occupied by a reddish feldspathic quartzite interlaminated with some dark, grayish-green, slaty graywacke. The strike of these is S. 35° W.; dip, S. 55° E. $<70°$–$80°$. The whole section, as exposed on this shore for a quarter of a mile to the northwest, shows evidence of the most profound disturbance and alteration. The quartzites, besides being hardened, are penetrated by veins of secondary quartz, both parallel to their bedding and reticulating in all directions, the whole being much squeezed and contorted. At the contact on the south shore both rocks dip southeast $<70°$–$75°$, the quartzite dipping into or under a red granitoid gneiss. Macroscopically, the quartzite is light gray in color, with a faint flesh-red tint on weathered surfaces. It seems almost completely vitrified and presents veins of secondary quartz running parallel with the stratification.

Microscopic Examination of the Quartzite.—Mr Ferrier, who examined a thin slice of this rock under the microscope, says:

"An exceedingly finely laminated quartzite, the lamination being marked by little strings of muscovite running between the quartz grains. It is evidently a highly altered clastic, in which the quartz has almost entirely recrystallized under

great pressure. It exhibits well-marked parallel structure, its component grains being drawn out in one direction. The larger drawn out grains show uneven extinction, as do also the finer-grained ones lying between them. Penetrating this quartzite were noticed many irregularly shaped intrusions of the coarse granitic gneiss."

Rocks between Daisy and Baby Lakes.—On the portage from Daisy lake into Baby lake the rocks strike N. 49° E. and the dip varies from 50° to 70°, but most generally the latter. The beds run in long, sweeping curves and are penetrated in places by intrusive gneissic material which shows up well against the darker feldspathic slates and quartzites. The Huronian rocks are much squeezed and altered. Immediately to the south of this portage rises a high hill composed of flesh-red granitic gneiss, the foliation being in general very distinct. Embedded in this gneiss on the very summit of the hill are patches of a dark greenish-gray, distinctly bedded, slaty rock, which have been clearly caught up in the gneiss during its irruption, and which are distinctly referable to some of the Huronian beds in the vicinity. A specimen illustrating the contact between these two rocks showed the slaty rock partly adhering to and partly embedded in the granitic gneiss.

Microscopic Examination of Contact Rock.—A thin section was examined by Mr Ferrier, who says:

"This section shows a contact between a coarse-grained granitic rock and a chloritic and epidotic schist. The granitic rock exhibits gneissic structure in the mass and may be classed as a coarse-grained biotite gneiss in which chlorite now replaces the original biotite. Intense cataclastic structure is shown, and a curious fact is that the feldspar, as often observed under similar circumstances, preserves its crystal form fairly well, whilst the quartz is all twisted and broken. Wülfing has suggested that this may be due to gliding planes (German gleitflächen) in the feldspar, allowing it to yield and be perhaps slightly changed in form but not broken, whilst the unyielding quartz would be all broken to pieces. The schistose rock presents no unusual features in its mineral constituents, but has, like the gneiss, been subjected to great pressure. Epidote is very abundant and angular fragments of quartz and feldspar occur scattered through a very fine-grained chloritic groundmass. The rock is probably of clastic origin."

A thin section obtained from about the center of the largest mass was also submitted to Mr Ferrier, who reports:

"A fine-grained amphibolite, consisting of chlorite, epidote, hornblende and a colorless mineral in the groundmass, which is probably feldspar, although satisfactory axial figures were not obtained. A little iron with titanite occurs in the section."

Rocks between Baby and Alice Lakes.—On the portage from Baby lake into Alice lake there is an apparent transition. The gneiss to the south

of the portage is a flesh-red, distinctly foliated granitoid gneiss. At the east end of the portage this passes upward into a very gneissic quartzite, whose distinct stratification is in marked contrast to the massive character of the gneiss. Under the microscope, Mr Ferrier says:

"This rock consists mainly of quartz and feldspar, with a little muscovite and epidote, and is a beautiful example of a sheared gneiss. It is cut by veins of chalcedonic quartz in many cases at right angles to the bedding."

This rock in turn passes upward into the more usual feldspathic quartzite whose clastic origin is undoubted. Both rocks dip S. 35° E. $<60°$, the quartzite dipping into or under the gneiss. At a small point on the eastern shore of Alice lake, just southeast of the portage into Baby lake is an exposure of yellowish-gray mica schist, with some dark green hornblende schist embedded in the gneiss, which rocks may represent an extreme alteration of the Huronian quartzites and graywackes.

WAHNAPITAL RIVER.

Contact Indicated by Character of the Rocks.—Continuing still further northeast the boundary strikes the Wahnapital river just below the Canadian Pacific railway bridge. The actual contact is not seen, but on the west side of the bridge are light greenish-gray feldspathic quartzites with some thin interlaminated bands of darker-colored sandy shale, the whole dipping N. 25° W. $<60°–70°$. On the opposite bank of the river, near the railway station, is a dark gray, evenly foliated micaceous gneiss, dipping S. 23° E. $<60°$. Ruby-colored garnets are exceedingly numerous, the crystals frequently measuring from a quarter to half an inch in diameter. The line of demarkation is occupied by the bed of the steam for a short distance, when it again strikes inland, running parallel to the general course of the river. At this place the recently constructed railway for the Emery Lumber company nearly coincides with the line of junction for a considerable distance, and the contact is seen at several places close to the road-bed.

The Huronian Representative.—The Huronian exposed at several small cuttings is represented by a dark gray, thinly-bedded quartzite, filled with joints, which cause it to fall to pieces under the hammer, often rendering it exceedingly difficult to obtain a satisfactory hand specimen. It is very highly altered, showing almost complete vitrifaction, often breaks with a conchoidal fracture, and is very similar to that described as occurring near the contact on Daisy lake. Further to the northeast the contact has only been examined at certain points, but it has been thought advisable to postpone any further description in this direction till it has been worked up in more detail. The foregoing description

has only covered the southeastern boundary, and it may be well to define the junction at a few other points.

ROCKS OF THE CONTACT BETWEEN CARTIER AND STRAIGHT LAKE STATIONS.

Between Cartier and Straight Lake stations, on the Canadian Pacific railway, there is an irregular patch or outlier of Huronian completely enclosed by gneiss and granite. The junction between the two rocks is seen just beyond Straight Lake station. The gneiss is very massive, coarsely crystalline, and very distinctly foliated, while the Huronian is represented by dark greenish-gray feldspathic shale and sandstone. The foliation of the gneiss in general corresponds with the strike of the shale, which is S. 84° E., dip S. 6° W. $<55°$. The sandstone and shale are altered into very glossy mica schist near the junction, become contorted and exhibit interlaminated nodose lines of quartz, veinlike in origin. These lenses of quartz are clearly secondary and in every case cause a bulging of the enclosing rock by their introduction, and have doubtless been formed by the silica set free in the genesis of the gneiss. Feldspathic intrusions are commonly met with in the sandstone and shale a considerable distance from the line of junction, while patches of the sedimentary strata have been caught up in the mass of the gneiss. Epidote is abundant, especially near the junction.

TWO ISLANDS NEAR THESSALON.

Contact previously described by Others.—During the early part of October last an examination was made of the contact as exposed on two islands close to the north shore of Lake Huron, about five miles east of Thessalon. As the water was rather high, only a few feet of the junction was exposed in each instance. The contact here was first described by Irving* in 1887 and later, in 1892, by Messrs Pumpelly and Van Hise,† but as the author's conclusions differ somewhat from those expressed by the above-named writers it was thought advisable to bring them forward at this time.

Difference in the Conclusions of the Author and other Writers recited.—The Laurentian or basement complex, as it has been called, is here represented by a granite gneiss through which has been intruded large masses and dikes of a dark greenish-gray, fine-grained diabase. This appears to be in turn cut by a flesh-red granite, although the frequent absence of

* Am. Jour. of Science, vol. xxxiv, pp. 207-216.
† Ibid., vol. xliii, pp. 224-232.

any sharp line of division between the two rocks would suggest the probability that both belonged to the same period of irruption, the more rapidly cooling diabase being intruded by the more slowly cooling granite mass. The diabase (according to Mr Ferrier) shows evidence under the microscope of having been subjected to great pressure, doubtless produced before the cooling of the granite magma, while the granite is comparatively free from any such evidence. The gneiss and granite contain numerous sharply outlined fragments of a dark-gray schistose rock which Pumpelly and Van Hise stated I classed as Huronian, whereas, in their opinion, these were pre-Huronian. From their article one would infer that there existed at this locality a large mass of these schists from which the smaller fragments had become detached, but beyond a mass of diabase such as described above and of which they make no mention, there seems to be no rock-mass from which these fragments could have been derived. These schists, however, do not in the least resemble the micaceous schists and quartzites described by me in contact with the Laurentian through the Sudbury district, for the former shows no trace whatever of clastic structure, while the fragmental origin of the Sudbury schists may readily be seen in the field or in a thin slice under the microscope. The banded appearance of the Thessalon schists points to a possibility of an original fragmental condition, but such must remain merely hypothetical, on account of their extreme alteration. The late Mr Alexander Murray, on his manuscript map of this district, frequently alludes to this granitic mass as "red and green trap" or "syenite," and both he and Sir William Logan* were of opinion that the granite was later than the Huronian strata with which it comes in contact.

The Huronian is represented by what Pumpelly and Van Hise characterize as a "great basal conglomerate," the detritus from which it was formed resulting from the disintegration of the gneiss and granite. As close an examination as possible was made of the line of junction, but the length of contact exposed is far too small to come to any undeniable conclusion. The very frequent angular or subangular outline of the included fragments in this rock point out the probability that the so-called conglomerate is in reality a volcanic agglomerate or breccia, whose fragments, thrown down in water, have become more or less rounded and mixed with finer arenaceous material. Besides, the conditions of contact on the two islands are essentially different. On one island the junction is so sharp and distinct that the line of division can be placed to the fraction of an inch. However, its abrupt change in strike ("at

*Geol. Canada, 1863, p. 58.

one place varying within a foot or two as much as 45° or 50° ") seemed to me to indicate the irregular outline of an eruptive mass rather than the sinuous outcrop resulting from prior erosion. On the other island, only a very short distance away, there is an apparent transition from the granite to the conglomerate. The conglomerate is very massive, so that the strike and dip could not be ascertained with any degree of certainty, and near the line of contact shows abundant signs of alteration. The contact between this granitic mass and the Huronian was also examined by the late Mr Alexander Murray at the southeastern end of Lake Pakowagaming. On a manuscript map to which I lately had access Mr Murray states that near the junction the Huronian is composed of a red-colored altered quartzite, slate and conglomerate, dipping north or away from the granitic mass at an angle of 80°. To the south and in immediate juxtaposition with the granitoid gneiss "the slates are corrugated and contain patches of red feldspar." A little to the northwest "the wrinkled and contorted quartzite and slate are cut by granite veins, mica and epidote." The rocks on the southwest side of this lake have all a high inclination northward, while on the northeast side the slates and quartzite are nearly if not quite flat.

Dr Selwyn has frequently pointed out, both in personal conversation and elsewhere, that the Huronian must be regarded as preëminently a pyroclastic series of rocks, and if this fact is borne in mind the occurrence of most of the so-called conglomerates will be more susceptible of explanation. These occur at various horizons through the series, and very frequently intimately associated with the massive diabases. They seldom, if ever, contain pebbles of gneiss, and the most abundant fragments seem to be of coarse red or gray syenitic granite. As agglomerates or breccias, some of whose fragments have become rounded by the action of water, they neither represent a want of conformity nor a great lapse of time, and simply occur as additional proofs of the intense volcanic activity which must have characterized this epoch.

The line of demarkation is very seldom a simple plane of division, the breccia present along the junction frequently covering a considerable space. It is therefore often impossible to draw an accurate line of division between these two rocks unless we assume that such a line should be placed where the two rocks are present in about equal proportion. The general correspondence of the gneissic intrusions with the stratification of the enclosing schists and the frequent lenticular outline and parallel disposition of the detached schistose fragments in the gneiss often resemble at first sight an alternating sequence of transitional beds. Again, the crystalline condition of the Huronian feldspathic and mica-

ceous quartzites near the line of contact, which frequently resemble in character and composition the more evenly laminated gneisses, has been referred to as evidence of such a transition; but even in such a case the bedded character of the Huronian is in strongly marked contrast to the granitic aspect of the gneiss.

Conclusions and Facts supporting Them.

In conclusion, then, the following facts seem to prove beyond a doubt the irruptive nature of this Laurentian gneiss and its magmatic condition at a time subsequent to the petrifaction of the Huronian sediments:

1. The diverse stratigraphic relations of the two rocks along their line of junction. Most frequently the Huronian strata dip into or under the gneiss, although often this position is reversed and the Huronian beds are seen superimposed on the gneiss with perfect conformity. In many instances the two rocks occupy vertical positions side by side and occasionally the gneiss has been seen dipping away from vertical Huronian strata. Huronian rocks have also been seen resting unconformably on the upturned edges of Laurentian gneiss. Sometimes, where the sinuosities of the line of outcrop of the gneiss were too abrupt to be followed by the stratified Huronian, the latter rocks have abutted on the gneiss as on an irruptive mass. These different phenomena can all be readily and naturally explained by the irruption of the gneiss, while on the hypothesis of an aqueous origin such explanation must be difficult and unsatisfactory.

2. The alteration of the sedimentary rocks along the line of junction is a feature that has been invariably noticed where the contact has been examined.

3. The inclusion of angular fragments in the mass of the gneiss which are clearly referable to the adjacent sedimentary strata. Near the line of junction these detached pieces have a clear and sharp outline, while further in the mass, where they have undergone partial fusion and absorption, their outlines are blurred and indistinct.

4. The occurrence of gneissic intrusions as well as more coarsely crystalline apophyses of pegmatite both interlaminated with and transverse to the bedding of the Huronian rocks. These intrusions are distinctly irruptive and can often be directly traced to their source in the larger area of gneiss in the vicinity.

5 The absence of limestones, slates or quartzites or, in fact, any species of rock indicative of ordinary sedimentation for the quartzites and mica schists sometimes seen interlaminated with the gneiss are simply quartzose and micaceous phases of the more common feldspathic gneiss.

6. The general character of the rock itself, which in appearance and behavior has far more resemblance to an ordinary eruptive granite with a foliated texture than an altered sedimentary rock. Sir W. E. Logan himself, in his notes of its occurrence on Lake Temiscaming, invariably refers to it as "gneissoid syenite," and the later Walter McOuat, of this survey, although he describes in his printed report an intrusive mass of syenite cropping out on Round lake at the head of Blanche river (north of Lake Temiscaming), yet on his accompanying manuscript map colors it as Laurentian gneiss, evidently deeming it of similar character and origin.

Everywhere this Laurentian gneiss is thoroughly crystalline and presents no structure that in any way suggests an alteration of clastic constituents. In many places the gneiss can be traced into obscure or nonfoliated areas which present the ordinary characters of true irruptive masses. The boundaries of these patches are very often illy defined and they pass insensibly into the ordinary gneiss. The frequent occurrence of dikes and masses points out a sequence of irruptions whose order it is often possible to determine over limited areas. The parallel arrangement of the component minerals and the alternation of coarser and finer bands often suggest the flow structure of certain eruptive rocks. The gneiss usually shows only slight evidences of secondary pressure, seen in the occasional dislocation of the feldspar crystals, in shearing and in cataclastic structure which has sometimes been developed. The Huronian schists, on the other hand, present abundant evidence of secondary pressure in the development of pronounced cataclastic structure, the presence of numerous shear planes, and the squeezed or drawn-out character of the quartz grains. Mr Ferrier, however, in his examination of two thin sections of the granitic gneiss to the south of Daisy lake, discovered the presence of most intense cataclastic structure, which must have been induced in the rock subsequent to its cooling, but as the schist in contact with the gneiss also exhibited this extreme phase of cataclastic structure, and as the stratified rocks in the immediate vicinity are so highly altered as to preserve hardly a trace of their original clastic structure, we may, perhaps, safely assume that both gneiss and schist have been subjected to this same immense pressure at a time subsequent to their coming together in their present position.

The Huronian system, therefore, may be regarded as the oldest series of sedimentary strata of which we have at present any knowledge in this region. The original sediments must have been laid down on a firm floor, whose composition, judging by the character of the Huronian rocks, must have been closely analogous to granite. It was doubtless the fusion and subsequent recrystallization of this granitic floor that gave

rise to the Laurentian gneiss. The immense pressure exerted by the weight of the superincumbent mass of Huronian strata and the crumpling, folding and fracturing of the comparatively thin and weak crust would all tend to sink the lower portions of the Huronian beneath the line of fusion, the submergence of which would produce conditions of contact such as have been described and which subsequent upheaval and denudation have exposed.

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THE ARCHEAN ROCKS WEST OF LAKE SUPERIOR*

BY WILLIAM HENRY CHATTERTON SMITH

(Read before the Society December 30, 1892)

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The Nomenclature Adopted.

In this paper I shall adopt the nomenclature employed for many years in the publications of the Canadian Geological Survey without at present making any attempt to justify it. The term "Archean," then, will be used, not in the restricted sense advocated by Geikie,* nor in that held by Van Hise,† but in its broadest application, as embracing all the rocks stratigraphically inferior to the Animikie rocks of Lake Superior.

The Region Studied.

Its Boundaries.—The portion of the Dominion of Canada to which attention is here drawn may be briefly described as the southern half of Rainy River district, in the province of Ontario, lying between our transcontinental highway and the international boundary, and the Lake of Woods, in the west, to the western boundary of Thunder Bay district.

Geologically complex.—It would be difficult to imagine a more interesting field or one that offers such facilities for geologic investigation, yet from the complexity of the structure of the rocks; from their antiquity; the tremendous movements they have suffered, as well as the changes they have undergone, and from the absence of all fossil remains, there is perhaps no part of the country about which so many difficulties cluster or in which lie so many pitfalls for the feet of the unwary, the hasty, or the dogmatic geologist.

Its topographic Character.—Physically, the country presents a vast network of lakes which with their connecting streams, afford a ready

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*Anniversary address before the Geol. Soc. of London on the volcanic rocks of England by Archibald Geikie, F. R. S., February, 1891.

† Am. Jour. Sci., vol. xii, p. 117.

means of transport by canoes. The lakes vary in size from mere ponds to great island-dotted sheets of water, of which the largest—the Lake of the Woods—embraces within its shore lines an area of hardly less than six thousand square miles. Probably one-fourth of the whole area is occupied by water. The land surface presents a tumbled and irregular succession of low, rounded hills, with here and there a sharp ridge or steep escarpment, but bold and rugged scenery is extremely rare. The surface has a gentle average slope from the watersheds to the drainage basins, and it is doubtful if the top of the highest hill is over seven hundred feet above the bottom of the lowest and deepest lake. This area occupies the southern margin of the Arctic basin.

Present Status of the Investigations.—A description of the distribution of the various rocks would be tedious and incomprehensible without constant reference to a good map. A large portion of the area is depicted on maps already published by the Canadian Geological Survey. A report upon and map of part of the remainder have been prepared by the writer and are now in press, while topographic and geologic materials relating to still another portion of the remainder have been collected and are now being prepared for publication. In addition to this, the writer has made several preliminary reconnoissances and surveys in those portions in which the field-work is incomplete.

Distribution and Relation of the Rocks.

Without entering into the details of rock distribution, there is one important feature of it which is worthy of attention.

TWO GREAT DIVISIONS AND THEIR EXTENT.

Lower Archean Series.—Separating the rocks for the present into two great divisions, (1) the lower granitic and syenitic rocks, more or less massive, and (2) the upper micaceous, hornblendic and trappean rocks, for the most part distinctly schistose, we find that the former occupy large rounded or ovoid areas which sometimes anastomose and the peripheries of which approach each other to within comparatively narrow limits. The longest axes of these areas are rudely linear to and parallel with each other and have a general northeast or east-north direction. In geographic extent these granitoid rocks cover considerably more than half of the whole country. It is interesting to note that such nuclear areas of granite are reported by Barlow north of Lake Huron and are mapped by Hitchcock in New Hampshire. As we pass from the Lake of the Woods in an east-southeast direction obliquely across the granitic areas we find that they become proportionately narrower and longer in

an increasing ratio as the shores of Lake Superior are approached. It would seem as if the Archean rocks after their consolidation in their present relations had been crushed together by a tremendous lateral force emanating from the southeast, the effect of this pressure becoming less and less as the distance from the supposed center of force increases.

Upper Archean Series.—Surrounding the nuclear ovoid and lenticular areas of granitic rocks as an irregular but almost uninterrupted network and dipping away from them generally on all sides lie the complex and varied rocks of the upper Archean series. The tendency of the two great divisions of Archean rocks to assume this relative distribution was first pointed out to me by Dr A. C. Lawson, and subsequent explorations in parts of Rainy River district unvisited by him have so far confirmed his opinion that such a relative distribution would be found to be characteristic of this region.

TERMS CONTCHICHING AND KEEWATIN SERIES SUGGESTED BY DR LAWSON.

The rocks occupying the ellipsoid synclinal troughs between the nuclei of granite have been separated by Dr Lawson (the classic authority on this region) into two divisions, for which he suggested the names of Contchiching for the lower and Keewatin for the upper. He has since proposed the name Ontarian to include these two groups. For the underlying granitic rocks the term Laurentian is used.

CHARACTER AND FIELD RELATIONS OF THE LAURENTIAN ROCKS.

The Laurentian rocks of this region are for the most part essentially granites. A gneissic foliation is often apparent and frequently well marked, particularly in the peripheral zones of the areas, while the central portions are usually more granitoid. The rocks vary in texture from fine- to coarse-grained and pegmatitic, and in color from light to dark gray and from pink to deep red. In composition they present many various characters. Usually the ferromagnesian mineral is biotite with more or less muscovite. Hornblende granites are not uncommon. The latter sometimes merge into the biotite granites by a gradual change in composition, but usually a sharp line of demarkation separates them. The relations in the field are sometimes suggestive of large brecciated fragments of hornblende granite caught up in the biotite granite, and sometimes of intrusions of the former into the latter. The relations of these two varieties of granite form an interesting problem for future study, but as yet the writer is not prepared to formulate any general theory concerning them; indeed, it is doubtful if any generally applicable theory is possible, as there is reason to believe that the hornblende granite is sometimes

the younger, sometimes the older and sometimes a contemporaneous rock, while it is not probable that there is any great difference in their respective ages. In this connection it is interesting to note that in Finland Dr J. J. Sedesholm * finds that there are two main series of granites, of which the earliest plageoclastic and hornblendic are eruptive in their relations to the Archean schists and younger than them; the other series, red garnetiferous muscovite microcline granites, the coarser varieties of which merge into a pegmatite, are the latest eruptive rocks of the Archean complex. On Hunters island there is a considerable development of red garnetiferous muscovite granite, very coarse-grained in places, the relations of which are not so clear.

Frequently the granites of Rainy River district are almost devoid of bisilicate, merging into red felsites and compact, massive gray feldspathic rocks approaching quartzites, which a well-marked system of cleavage planes sometimes cuts into regular rhomboidal blocks.

Again the bisilicate is frequently altered to chlorite. The granites sometimes exhibit a distinct porphyritic structure, evinced by the large crystals of feldspar in a finer-grained groundmass. These porphyritic granites have often a distinct gneissic foliation.

For convenience of reference the separate areas of granite in this region have received distinctive geographic designations in the reports of the Canadian Geological Survey. One of them, which in the forthcoming report on the Seine River district will be named the Seine area, is remarkable for the predominance of plagioclase in the rocks of its southwestern portion; this, in association with chlorite, which is probably derived from hornblende, characterizes the rock rather as a quartz-diorite than a granite. The microscopic examination of the rocks of this area is not yet complete, but in the field there seems to be a gradual passage of the quartz diorite or chloritic plagioclase granite into the ordinary orthoclase granite; certainly the writer has so far been unable to find anywhere a sharp line between them. Plagioclase in greater or less proportion occurs in many of the granites of the whole region.

RELATION OF CONTCHICHING AND KEEWATIN SERIES TO LAURENTIAN GRANITES.

Before proceeding to a consideration of the rocks of the Contchiching and Keewatin series, it would be well to refer briefly to the relations which the Laurentian granites bear to them.

Contact Phenomena Criterion of Relative Age.—In the absence of paleontologic evidence the most important criterion that remains for the determination of the relative age of contiguous rock series are the features

* The Archæan Eruptive Rocks of Finland, by Dr J. J. Sedesholm.

of the contact between them, as justly observed by Barlow.* These features have been so clearly and precisely described by Lawson in his official reports that it is unnecessary to repeat them here; suffice it to say that I have found his description to apply to all the contacts that I have observed in the portions of Rainy River district not reported on by him. While it is true that some of these features, such as the intimate interbanding of the gneisses or foliated granites and the schists, may be regarded as analogous to the intimate interbanding frequently observed in sedimentary strata; and while it is also true that some other features, such as the angular fragments of one rock embedded in the other may, where these brecciated zones are narrow, be due to the shattering of the rocks along a line of fault, still there are many contact features which cannot be accounted for on any theory which holds to the sedimentary origin of the granite gneisses; such features are the apophyses of granite which can be traced directly into the main mass, and which sometimes are parallel to the planes of schistosity of the rocks which they invade and sometimes cut across these planes. It must not be forgotten that the phenomena that have been described by Lawson are not isolated instances of peculiar occurrences extending in the aggregate over but a small proportion of the contact line, but are typical examples everywhere characteristic of the contact, and the absence of which is rare.

Character of the Contact.—A comprehensive and careful study of the contact of the Laurentian and Ontarian rocks of Rainy River district forces us to the conclusion that it is eruptive or irruptive in character.

Origin of the Laurentian Rocks.—Either, then, the so-called Laurentian rocks of this district have been irrupted in the form of a plastic magma into the overlying rocks after these had become consolidated (the attractive theory of Dr Lawson) or else a remarkably continuous series of later eruptions have been extruded in the planes of contact between the Laurentian and Ontarian rock, presumably the line of weakness.

Laurentian Rocks the younger.—This latter theory is open to so many and serious objections that it has few adherents. If the former theory is correct, the granite gneisses, with regard to all the relations of which we have any certain knowledge, are younger than the rocks which they invade, and, as they pierce both the Coutchiching and Keewatin, their present condition is of post-Keewatin origin.

Selection of the Term Laurentian based on imperfect Knowledge.—The earlier descriptions of the Laurentian rocks of eastern Canada must be regarded as imperfect, and the contact features have not been described. They are therein spoken of as metamorphic sediment inferior to the

* The Contact of the Laurentian and Huronian Rocks North of Lake Huron, by A. E. Barlow, Am. Geologist, vol. vi, no. 1, p. 19. Also ante, pp. 313–332.

Huronian, and the writer is not aware of any general contradiction that has been given to the assumption by more recent writers on Quebec and eastern Ontario. For this reason the application of the term Laurentian to the irruptive granite gneisses west of Lake Superior is perhaps unfortunate, as involving a hasty and undetermined correlation.

Considerations affecting the Status of the Term Laurentian.—Admitting for the moment that the Laurentian rocks of Quebec are of sedimentary origin, and that the granite gneisses west of Lake Superior are irruptive in their character, it is still possible, nay, probable, that the two are contemporaneous in age and identical in primal origin on the assumption that these latter rocks but represent metamorphism carried to the extreme of fusion (as a consequence of the relatively higher local elevation of the isotherms), resulting in their irruption into the overlying Huronian strata and their recrystallization in the form of consolidated magma. The question, then, of the most appropriate name for these western Ontario granites becomes a question of the era of our chronology.

Shall we date them from the time of their intrusion into the overlying strata, or shall we go further back into their obscure history and date them from the time when in all probability they formed the solid floor on which the Contchiching and Keewatin rocks were laid down? In other words, shall we call them Huronian (the term is here used to include all the rocks between the fundamental granites and the Animikie) because they are intrusive into Huronian strata, or Lurentian on the above assumption of their genetic identity with the Laurentian gneisses of the east? If we can regard the irruptive origin of the present relations of these granites to the Upper Archean rocks as indubitably established, it would seem unwise to go behind this fact into the uncertain realm of theory to justify for them the name "Laurentian," as the term "Huronian granite" embodies a more precise statement of our conclusions.

But the passage of the granitic phases into the gneissic is so gradual, the lithologic similarity between the gneisses of the east and of the west is so marked, and their geographic continuity so highly probable, if not an established fact, that it is difficult to conceive of any great genetic difference or of any considerable geologic interval between their respective ages. The applicability of the term Laurentian, as applied to the granites of Rainy River district, is also supported by the fact that as the Laurentian of Quebec is being reëxamined in the light of modern knowledge, the opinion is gaining ground that at least the "Lower Laurentian" rocks present characters precisely analogous to these of the west. Perhaps some of the rocks that have hitherto been called Upper Laurentian in the east are the equivalents of the Contchiching series of Lawson, although they differ from them in some lithologic characters.

THE CONTCHICHING SERIES.

Rocks composing it.—The Contchiching series consists essentially of fine-grained evenly laminated biotite gneisses, light gray in color; of fine to coarse grained mica schists, generally highly feldspathic and sometimes very quartzose, from dark gray to light gray in color and brownish or "rusty" weathering, and of fine-grained hornblendic mica schists.

Position and Relation of its Rocks.—In the southeastern part of the district they occupy a position always intermediate between the granite gneisses, which in the contact zone generally invade them in parallel bands, apophyses and dikes, and the hornblende schists and altered traps at the base of the Keewatin, which overlie them in conformable position. They frequently merge into these by a gradual change in mineral composition across the strike. N. H. Winchell * refers to a gradual and conformable transition between Vermiline (Contchiching) and Keewatin.

In the Lake of the Woods there is a series of mica schists which, according to Dr Lawson's descriptions,† are closely similar to those which he subsequently separated from the Keewatin and designated under the name of Contchiching. In his hypothetical sections of this district, the accuracy of which, however, he does not insist upon, he relegates these mica schists to the highest position in the Keewatin scale. By a reference to the map, however, it will be seen that in their most important development they occupy a position on the margin of the Keewatin trough in the southwestern part of the lake and in direct contact with the Laurentian granites. While developments of these mica schists are found in interior portions of this Keewatin trough, such a position may easily be accounted for on the assumption that they represent the crests of anticlinal folds exposed by denudation. Indeed, the foldings and disturbances in this trough have been so great that almost any position in the scale may be attributed to the mica schists of this complex series. The inference is strong that these rocks in the Lake of the Woods are the equivalents of the Contchiching series of Rainy lake.

Its Thickness.—In this latter region Dr Lawson attributes to the Contchiching series ‡ a maximum thickness of from 24,000 to nearly 29,000 feet. On a similar interpretation of the structure east of this, in the western part of the Hunters Island region, about the same thickness may be inferred. The writer, in his report on this latter region, now in press, states at some length his reasons for doubting that these rocks have such

* 17th Ann. Rep. of the Geol. and Nat. Hist. Survey of Minnesota.

† Report on the Geology of the Lake of the Woods, by Andrew C. Lawson. Part C E of the Ann. Rep. Geol. Surv. of Canada, 1885.

‡ Report on the Geology of the Rainy Lake Region, by Andrew C. Lawson, M. A., Ph. D., part E, Ann. Rep. Geol. Surv. of Canada, 1887–'88.

an enormous thickness. Without recapitulating these reasons here, it will be sufficient to state that in his opinion the Contchiching series nowhere in the Rainy River district attains a greater thickness than 9,000 feet, the greater apparent thickness being due to multiple folding.

Clastic in Origin.—The clastic origin of the gneisses and mica schists of this series can hardly be doubted by any one familiar with them in the field; their fine and even lamination and their bedded appearance affords in itself almost conclusive evidence and the microscopic descriptions of them by Lawson strongly support this view. Their mineral composition indicates derivation from the denudation of a granitic floor.

Structural Conformity between Contchiching and Keewatin.—Between the Contchiching and the Keewatin rocks there is everywhere a strict conformity of structural relations. In rocks which have suffered such great mechanical deformation, however, it must always be borne in mind that much of the original structure may have been obliterated and replaced by subsequent cleavage, so that it is hazardous to state that because there is now strict parallelism in the existing schistose planes of contiguous rock series that this necessarily indicates original conformity. Dr Lawson argues an interval of erosion between the Contchiching and Keewatin series from the presence at the base of the Keewatin of a conglomerate on the Seine river and on Rat Raot bay of Rainy lake. The former of these conglomerates is for the most part an integral portion of the Keewatin series and for only a small proportion of its development does it occupy a strictly basal position, so that it rather marks a local break in the Keewatin itself than one between the Keewatin and Contchiching, serving in a measure rather to bind these series together than to separate them. The so-called conglomerate of Rat Raot bay is mapped as lying wholly between the two series, but from what the writer has seen of it he regards it as rather of volcanic than of detrital origin.

The Contchiching and Keewatin lithologically Distinct.—That the Contchiching series is lithologically distinct from the Keewatin, and marks a period subsequent to which a profound change in the conditions of rock formation took place, cannot be denied, and the term is useful and appropriate as designating a well-marked and perhaps the most important formation of an extensive series; but the Contchiching cannot be regarded as in any respect coëqual or coëxtensive with the Keewatin. There is no stronger evidence of unconformity between the two than there is between any two distinct horizons of the Keewatin, particularly where conglomerates are developed, and the Contchiching would seem to be therefore essentially the basal portion of the Keewatin.

CONDITIONS UNDER WHICH CONTCHICHING AND KEEWATIN WERE FORMED.

The close of the period during which the Contchiching rocks were laid down ushered in an era of intense and long-continued volcanic activity, interrupted perhaps and succeeded by periods of compensative quiescence during which erosion and sedimentation took place; but during Keewatin times no certain evidence of any great or extensive crustal movements is afforded. The whole Keewatin and Contchiching series seems to have been folded by one great and perhaps simultaneous upheaval of the original floor. This folding marked the close of the Keewatin epoch. Barlow* suggests that the concentric lamination in the ovoid areas of granite gneiss indicates that the forces of upheaval acted from certain centers; this may be so, but the phenomenon may also be accounted for by the flow of the magma being directed by its proximity to the hard schists. It may be more correct to say that the folding of the schists was caused not so much by an upheaval of the subcrustal magma acting from centers of force as by the crumpling, due to lateral compression, forcing their synclinal folds into the plastic magma.

THE KEEWATIN SERIES.

Rocks composing it.—The Keewatin series consists for the most part of plutonic, volcanic and pyroclastic rocks. While some of the upper members seem to be more or less altered aqueous sediments, the proportion of undoubtedly clastic rocks is small.

Its stratigraphic Succession.—Unfortunately the microscopic study of these rocks is as yet incomplete. The solution of their stratigraphic succession is confronted by almost insurmountable difficulties, and only a general suggestion as to the sequence of broad and ill-defined groups can be offered. The line of demarkation between the numerous horizons is seldom clear, and where those horizons can be separated at all they are not always found to occupy the same relative position. They are seldom very persistent, and overlap each other as more or less attenuated lenticular bands. I know of no place in this district presenting a complete section of the Keewatin. The most important and complete development of this series is found in the Lake of the Woods and Rainy Lake regions.

Speaking generally, then, the basal members of this great series consist of dark green or black crystalline hornblende schists, generally fine-grained, and which are sometimes seen to merge into the mica schists of the Contchiching; of dark and light green altered traps, generally massive, but sheared and broken by pressure and sometimes rendered schistose; of green chlorite schists, which sometimes seem to be altered hornblende schists and often again are almost undoubtedly but highly

* Am. Geologist, vol. vi, no. 9, July, 1890.

schistose phases of the altered traps. At the top of the series are found soft, fissile, light-gray schists, micaceous schists and some altered clay slates. Between the rocks which may be always recognized as the basal rocks and those which appear to be always in the highest position in the scale are a complex group of volcanic detritals, agglomerates, tuffs and trap, ashes, felsite schists, sericite schists and fine-grained evenly schistose quartz porphyries. Some of these rocks were probably thrown out as volcanic ejectamenta and, falling in the waters of ancient lakes, were sifted and stratified by their restless motion. In this way perhaps some of the conglomerates have been formed. Others again are probably but volcanic breccias, of which the harder fragments have been more or less rounded in their passage through the vents and in subsequent movements before they became consolidated in the matrix. On the Seine river the chlorite schists in one locality contain abundant lenticules of quartz which are often very wide in proportion to their length, giving the rock a conglomeratic aspect. These again are sometimes lengthened out and appear as irregular lenticular quartz stringers. While some of the Keewatin conglomerates have the appearance of being true sedimentary depositions on old beaches, there is yet a degree of uncertainty as to their character and origin. These are for the most part local in extent and narrow in development and occur at various horizons in the middle and lower portions of the Keewatin. They may, as Sir Archibald Geikie* says, "undoubtedly indicate local disturbance connected perhaps with terrestrial readjustments consequent upon the waning of volcanic energy;" but it is extremely doubtful if in this part of the country they mark a great or continuous break dividing the Keewatin rocks into a lower and upper division at any recognizable horizon. Their significance seems to be merely local. Professor Van Hise† attaches importance to several described occurrences of conglomerates. In only one case, however, was an undoubted unconformity observed below the conglomerate, and this may be accounted for by the assumption of a fault. The collective extent of all the conglomerates described by these authors is insignificant in comparison with the area to which they would apply their conclusions. The absence of unconformity of structure between the conglomerates and underlying rocks, which is likewise, so far as observed, in the Canadian area northwest of Lake Superior an invariable rule, is in itself a significant fact, for the same cleavage-producing forces which might entirely obliterate all original structure in the fine-grained schists would not

*Anniversary address before the Geological Society of London on "The volcanic Rocks of England," 1891.

†"An Attempt to harmonize some apparently conflicting Views of Lake Superior Stratigraphy," Am. Jour. Sci., vol. lxi, p. 117, and "Observations on the structural Relations of the Upper Huronian, Lower Huronian and Basement Complex on the north Shore of Lake Huron," Am. Jour. Sci., vol. lxiii, p. 224. This latter paper was prepared in collaboration with Mr Pumpelly.

obliterate all traces of the original bedding planes in these coarse clastics. In so far, therefore, as the conclusions of Van Hise and Pumpelly are applied to the lower Archean rocks of Canada northwest of Lake Superior, the writer regrets that he finds himself at variance with these eminent authors, being a follower of Geikie in the belief that conglomerates do not necessarily mark any stratigraphic discordance in these old rocks. These conglomerates have not yet received the attention which they deserve, and we may hope that a more detailed and extensive study of them will elucidate some of the problems of Archean geology.

THE STEEP ROCK SERIES.

Discordant in Character.—The Laurentian and Ontarian rocks hitherto considered do not embrace all the presumably Archean rocks found in this country. Mr Smyth, late of the United States Geological Survey, recognized and described* a discordant series, which is almost undoubtedly of post-Keewatin age, about the shores of Steep Rock lake.

Its Stratigraphy.—This Steep Rock series consists of the following horizons in ascending order:

I. Basal quartz conglomerate, sometimes represented by a massive quartzite, estimated to be 430 feet thick.

II. Lower limestone, dark and light bluish-gray, with the bedding marked by cherty seams, weathering in relief. The upper part of this formation is a characteristic breccia of limestone and trap fragments in a matrix of consolidated calcareous floor; thickness, 500 to 700 feet.

III. About 600 feet of a very soft, fissile, dull green, pyritiferous, volcanic ash, containing beds of jasper and iron ore.

IV. Interbedded, coarsely crystalline, greenish-gray traps (probably diorite), with layers of dynamic green schists; thickness, about 1,000 feet.

V. Upper calcareous green schist, with thin seams of limestone, 600 feet thick.

VI. Upper conglomerate, varying from hydromica schist, with many grains of quartz, to a rather coarse conglomerate. The inclosed pebbles consist entirely of quartz and granite; maximum thickness, 100 feet.

VII. About 1,400 feet of light greenish-gray, close-tectured, massive greenstone and greenstone schist.

VIII. Agglomerate, 300 feet thick.

IX. Dark gray clay slate, of unknown thickness. Higher horizons probably occupy the country to the south of the lake.

Such are briefly the descriptions of horizons by Smyth in his admirable memoir. The work since done by the writer in connection with the rocks of this series suggests no important modification of them.

*"Structural Geology of Steep Rock Lake, Ontario," Am. Jour. Sci., vol. xlii, p. 317.

A folded Syncline.—The discovery of a well-marked band of brownish gray clay slates very similar to those on the shore of Steep Rock lake, striking in an easterly direction and dipping to the north, though at high angles, which lie about a mile and three-quarters south of the southern bend of the lake, and which would seem to represent the southern upfold of the horizon (IX), would indicate that the series must be regarded rather as a folded and buckled syncline than as a tilted and buckled monocline. This simplifies the conception, as it answers the somewhat troublesome question as to what has become of the corresponding half inferred by the supposed monocline. The country south of the middle bend of Steep Rock lake and lying between its western and eastern long-extending arms is extremely rugged and is almost impassable, so that the sequence of the rocks could not be worked out.

Its Thickness.—If the conclusions drawn from the discovery of the clay slates south of the lake are just, the higher horizons inferred by Smyth seem to consist principally of coarsely crystalline traps and light greenish-gray, close-textured traps, with their schistose mechanical derivatives paralleled by horizons IV and VII, and about 4,000 feet must be added to the total thickness of the series as estimated by Mr Smyth.

Its Relation to the Laurentian and Keewatin.—This extensive series appears to have been laid down upon the eroded surface of the Laurentian and Keewatin rocks long after the irruption of the Laurentian granites.

Effect upon it of orographic Movement.—It appears, then, as pointed out by Smyth, to have been folded by crustal movements into a cynclinal trough, whose axis had a northwest and southeast direction. Subsequent to this a great lateral pressure, acting in a direction nearly parallel with this synclinal axis, has buckled the whole series in a horizontal plane and crushed and sheared the underlying basement rocks. Relief from this pressure was also afforded by a slipping of the rocks in the vicinity of Northwest bay of Steep Rock lake, indicated by a complicated series of faults which are clearly recognizable in the Steep Rock series and may be inferred by the distribution of the Laurentian and Keewatin rocks to the north and to the south. These faults indicate a horizontal dislocation of nearly 7,000 feet in the aggregate, and that the vertical dislocation must have been of even greater extent is inferred by the volume of these newer rocks which were faulted below the present level of denudation.

Older than the Animikie.—The lateral pressure which produced these faults and the remarkable structure of the Steep Rock series acted in a northwest and southeast direction, and it is most highly probable that it was the same pressure which, acting from a center of force to the southeast, produced the lenticular character of the granitic areas referred to in an earlier part of this paper. As the Animikie rocks northwest of Lake

Superior exhibit no trace of this or of any lateral pressure, the inference is strong that the Steep Rock series is older than the Animikie.

Its Unconformability not always Observable.—The unconformity between the Steep Rock series and the Laurentian dioritic granites and anticlastic chloritic schists of the north and east shore of Steep Rock lake admits of scarcely any doubt, but the unconformity above the Keewatin schists of the Seine river to the southwest is not at all obvious. Lithologically the green altered traps and schists of the two series are strikingly similar and could not probably be separated by the most careful study, but it is significant that west of the faults of Steep Rock lake the most careful search on the part of both Mr Smyth and myself has been rewarded, as far as I know, by the discovery of only one exposure (and that of a few square yards in extent) of rock that can with any degree of certainty be regarded as representing the characteristic limestone formation of the Steep Rock series. This was found by the writer on the north side of Seine river, about four miles west of the mouth of the Atic Oban river. Farther down the Seine river some thin bands, which are very doubtfully representatives of the upper calcareous formation (VI), are seen in two or three localities, but these are of trifling extent. West of Steep Rock lake and north of Seine river are some important developments of traps, light greenish-gray and fine-grained, with some dynamic schists, probably derived from them, which are macroscopically quite similar to those grouped under horizon VII. We would expect, however, to find the remains of the eruptive members of this series among the lower rocks of the neighborhood. It seems, therefore, that to the west the Steep Rock series has been faulted up and swept away, and whatever significance may attach to discordance of present structural relations on opposite sides of a fault plane, these relations point to the conclusion that this series lay unconformably on the Keewatin.

The Unconformity a Measure of geologic Time.—If the above interpretation of the structure and relations of this series is correct, it is most interesting, as it is the most important if not the first recognized undoubted unconformity in the Huronian system of the Canadian geologists. As the period of time predicted by this series is enormous, it strongly emphasizes Lawson's statement that the erosion interval between the Keewatin and the Animikie is the greatest in American geology.

Its Relation to the Atic Oban Series.—To the south the Steep Rock series appear to have been removed by the same causes. South of the southwest arm of Steep Rock lake it appears to be cut off by the quartz porphyries of Smyth's tentative Atic Oban series, but the writer's subsequent examinations have convinced him that the southwestward extension of these quartz porphyries is not great and almost certainly

does not reach to the probable southern extension of the great fault in the western part of Steep Rock lake. These quartz porphyries become distinctly finer grained in the vicinity of the Steep Rock series to the northwest and west and less certainly so as the massive altered traps to the south are approached. They are extremely massive and coarse-grained in the intermediate portions. The altered traps to the south, the writer thinks, belong to the Keewatin, being succeeded in descending order by chloritic, hornblendic and micaceous schists and Laurentian granites. The quartz porphyries appear to be a unit mass erupted, since the deposition of the Steep Rock series, along a probable fault plane or line of contact between the underlying Laurentian and Keewatin rocks, presumably the line of weakness. They extend several miles to the east, north of and rudely parallel to the general direction of the Atic Oban river, and send out long apophyses northeast into the Seine granite area. Their contact with the "greenstone" to the south seems to be less irregular.

The introduction into the already confused Archean nomenclature of the unnecessary term "Atic Oban series" is to be deprecated, as it can only include this unit mass of eruptive rock, the correlation of which with other similar masses must always be uncertain.

Whether the eruption of these quartz porphyries preceded or succeeded the great oratechnic movement which buckled the Steep Rock series must remain as yet an open question. Their massive character on Margaret lake favors the view that they are of later date than this movement. On the other hand, they are here found in their broadest development, and their mass and perhaps a superior hardness may have enabled them to resist this pressure. In the terminations of the apophyses which they send into the Seine area of granites the rocks are found to be intensely crushed; and if the isolated bands of crushed and sheared quartz porphyries which are found in the Seine area northeast of Steep Rock lake are of the same age, they must have antedated this lateral pressure.

Economic Geology of the Archean.

Present Knowledge superficial.—Our knowledge of the economic geology of the Archean rocks is purely superficial, as no real mining has been done and no facilities are thus afforded for an exhaustive study of the ores and their intimate relations. The writer cannot refrain from expressing his opinion here that the laws of Ontario are primarily to blame for this stagnation in mining. As they encourage every evil tendency of mining speculation and discourage every attempt at scientific exploitation and healthy development, the mineral wealth of this undeveloped country remains unimproved and unremunerative.

Iron Ores.—Iron ores, in many places known to be rich and in others reasonably presumed to be so, below the surface are more or less abundant in three distinct horizons. During the last two seasons the writer has discovered magnetic ores, free from sulphur, phosphorous and titanic acid, in micaceous schist, probably of Contchiching age. These ores on the surface are of low grade and intimately interbanded with the inclosing rock, but they may fairly be regarded as indicating extensive ore bodies below the surface, probably of great economic value.

The iron ores in association with the traps near the base of the Keewatin in the Hunters Island region and north of the Atic Oban and Seine rivers are well known to western geologists. In the former locality they are associated with jasper and are the extension of those great ore bodies which form one of the wonders of Minnesota. In the latter locality the ores are known to exist in extensive deposits and are of very high grade, running as high as 70 per cent of metallic iron. Here as a rule no jasper is associated with them. The ores of the same belt of Keewatin rocks in which these occur, where found in the vicinity of Rainy lake, are often so highly titaniferous that they are of little value in the present stage of metallurgic science, but this seems to be but a local phase due to local causes.

The ores of the third horizon of the Steep Rock series are somewhat problematical, but there are indications of extensive ore bodies in these rocks.

Gold.—Gold has been mined in the Lake of the Woods in a feeble and half-hearted way for many years, but the industry has languished under many difficulties and misfortunes. Most of the quartz, however, is extremely rich, but the mining in almost every case has been conducted unscientifically, and the geologic problems connected with it have never been properly worked out. Most of the gold-bearing quartz veins have been found in the Keewatin rocks; but some of them, and these of the richest, occur in granites, probably eruptive, usually coarse-grained and chloritic, and somewhat resembling the quartz porphyry of the Atic Oban river. These latter rocks are frequently found to contain very rich auriferous quartz veins. The gold-bearing quartz porphyries of Harold lake (north of the Seine river and about three miles west of Steep Rock lake) are probably of the same age as the Margaret lake quartz porphyries, though geographically the two are disconnected. It is possible that the granites in the Lake of the Woods, which contain auriferous quartz veins, are of the same era of eruption as these.

Nickeliferous Diorite.—Nickeliferous diorite has been recently discovered in the vicinity of Rat portage, but as yet none has been found containing a high percentage of nickel.

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THE LAURENTIAN OF THE OTTAWA DISTRICT*

BY R. W. ELLS

(Read before the Society December 29, 1892)

CONTENTS

VIEWS OF EARLIER WRITERS.

In discussing the structure of the Laurentian rocks, as developed in the valley of the Ottawa river, their characteristics, as given in the first report of the late Sir William Logan, in 1845–'46, on "The Laurentian of the Upper Ottawa," may here be presented. After stating that a low anticlinal crosses that river between the mouth of the Mattawa and the foot of Lake Temiscamingue, he says:

"The lowest rocks which this undulation brings to the surface are of a highly crystalline quality belonging to the order which in the nomenclature of Lyell is called metamorphic instead of primary, as possessing an aspect inducing the theoretic belief that they may be ancient sedimentary formations in an altered condi-

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tion. Their general character is that of syenitic gneiss. Their general color is reddish, and it arises from the presence of reddish feldspar, which is the prevailing constituent mineral. The feldspar is, however, often white or bluish-gray. The rock is in no case that I have seen without quartz. Hornblende is seldom absent and mica very often present. The prevailing color of the quartz is white, but it is often transparent or translucent. The hornblende is usually black and sometimes green. The mica is often black, frequently brown, and generally of a dark tinge. The rock (carefully distinguished from dikes) is almost universally small grained, and though the constituent minerals are arranged in parallel layers, no one constituent so monopolizes any layer as to exclude the presence of others, but even in their subordinate arrangement there is an observable tendency to parallelism; a thick bed of reddish feldspathic rock, for example, will, in section, present a number of short dashes of black hornblende or black mica, all drawn in one direction, destitute of arrangement apparently, except in regard to their parallelism, or it will be marked by parallel dotted lines, composed of these minerals. The constituents of these lines will be interrupted irregularly, and before one ends another will commence above or below it, the lines interlocking among one another. Sometimes these continuous parallel black belts will run in the rock for considerable distances or it will be barred by parallel streaks of white quartz or white feldspar, in which, as well as in the red part, these dark and dotted lines will occur. The same description of arrangement will be found where the whole ground of the rock is white instead of red, and then the red feldspar will occasionally constitute streaks. There is no end to the diversity of arrangement in which the minerals and the colors will be observed, but there is a never-failing constancy in respect to their parallelism, which, however, though never absent, is sometimes obscure."

In the Geology of Canada, 1863, page 23, it is stated that—

"Very large masses of this rock are frequently coarse grained. These are usually very feldspathic, the feldspar being in cleavable masses, often attaining an inch or more in diameter, which the mica and the quartz, often accompanied by hornblende, and the former sometimes replaced by it, are distributed among the feldspar in such a manner as to give a reticulated aspect to the surface of the rock. Beds of this character are sometimes thin, but when thick, which they usually are, might on first inspection be mistaken for intrusive igneous instead of altered sedimentary masses.

"The dip of the strata is generally at high angles, but many undulations and contortions exist. Some of the former give northern; others, southern dips."

Present View.

It will be seen from the preceding quotations that the views then held as to the Laurentian rocks regarded them as almost entirely of sedimentary origin, and that these were subsequently altered by metamorphism. While it is evident from the clearly interstratified character of many of the beds, such as gneiss, quartzite and limestone, that these have been produced from true sedimentary deposits in the same way as the Potsdam and Calciferous of a later date, it has been very conclusively pointed out

by the work of Lawson around the Lake of the Woods and by that of Bell and Barlow in the Sudbury district that a very considerable portion of the more syenitic mass must now be regarded as truly of eruptive character. These masses, which are sometimes syenitic or granitic, in places assume a gneissic structure, a peculiarity also sometimes observed in the more recent syenitic and granitic masses of eastern Quebec and New Brunswick. The same conclusions as to the origin of much of the so-called syenitic gneiss will apply to large portions of the rock in the area north of the Ottawa more particularly under consideration.

Earlier Divisions of the Laurentian.

In the earlier reports and on the great geologic map of Canada, 1866, the Laurentian was divided into two portions—a lower, comprising the gneiss and limestones, and an upper, which embraced the great areas of anorthosite or labradorite rocks, found more particularly at that date to the northwest of Montreal, near Saint Jerome.* No attempt was at that time made to separate the calcareous portion from the gneissic, and in fact the former was then regarded as an integral part of the whole, occurring as regularly interstratified beds often of great thickness, at different points in the column representing the entire thickness of the Laurentian rocks.

Scope of the Present Paper.

In this paper we propose to reconsider the typical section upon which the great thickness of the supposed sediments, comprising a total of over 32,000 feet, was based, and to show that, in the light of the explorations carried out during the last fifteen years, certain modifications of the arrangement of strata as there laid down must be made.

The Laurentian Limestone and Gneiss.

The development and distribution of the limestones of the Laurentian plays a very important part in the determination of the structure and thickness of the whole, since in some places the calcareous bands are exceedingly limited, having a thickness of not more than five to ten feet, or even less, while in other places this thickness increases to several hundreds of feet. Thus, in a section published by Logan in 1845 of the High falls of the Madawaska, representing a thickness of 1,350 feet, the limestone is noted as occurring in seven bands, the thickness of which varies from less than one foot to nineteen, in which latter, however,

*See map published in atlas, Geol. Canada, 1863.

several corrugated bands of gneiss are included, the whole thickness of the limestone representing less than forty-six feet, and the greatest development of the calcareous members being near the top of the section. The gneiss is of several kinds, but mostly reddish, grayish, hornblendic or rusty. From the character of the section, it is evident that the greater part lies below the calcareous portion of the system or forms the lowest part of that division.

Origin of the Term Laurentian.

The term Laurentian, as applied to the lowest system in Canadian geology, first appears in the report for 1852–'53. It was founded on the name Laurentian given by Mr Garneau, of Quebec, to the range of hills on the north side of the Saint Lawrence river, which are composed principally of the rocks of this system. In this report the description of the country west of the Ottawa and north of Kingston on the Saint Lawrence is by Mr A. Murray, and therein he describes a similar series of grayish and reddish gneisses with crystalline limestone. The latter, however, has a much greater development than in the section on the upper Ottawa. Intrusive masses of red granite are noted at various points, which cut transversely across the gneiss. The structure of the limestone in places is held to be interstratified with the gneiss, but at other points it appears on either side of an anticlinal in the gneissic rocks.

Sir W. Logan's Investigation of the Laurentian Structure.

The principal work on which the structure of the Laurentian has been based for many years was done by Sir William Logan and his assistant in 1853, in the Grenville district, north of the Ottawa river. This area is situated about midway between Ottawa and Montreal, and the difficulties he encountered in the attempt to unravel what has long proved a puzzling problem were very great. The country at that time was almost entirely a wilderness, small sections only being opened up for settlement, densely wooded and, in places, largely drift-covered. Short traverses were made along some of the larger lakes and on the principal streams or by means of tracks cut through the forest. Of the difficulties as to the structure, Sir William says:

"Bands of crystalline limestone are easily distinguished from bands of gneiss, but it is scarcely possible to know, from mere local inspection, whether any mass of limestone in one part is equivalent to a certain mass in another. They all resemble one another more or less lithologically, and although masses are met with, running for considerable distances rudely parallel to one another, it is not yet

certainly known whether the calcareous strata are confined to one group, often repeated by sharp undulations, or whether it is probable there are several groups, separated by heavy masses of gneiss. . . . The dip avails but little in ascertaining this, for in the numerous folds with which the formation is wrinkled these dips must frequently be overturned, and the only reliable mode of pursuing the investigation and of making even the limestone available for working out the structure is to patiently and continuously follow out the outcrop of each important mass in all its windings, as far as it can be traced, until it becomes covered up by superior unconformable formations, is cut off by some great dislocation, or disappears by thinning away to nothing."

The attempt was therefore made in this district to work out the structure of the Laurentian limestone bands by tracing out their outcrops, an undertaking which, in the unsettled and wooded character of most of this region, was to a large extent impossible of accomplishment, especially in a country to a large degree occupied by rugged ranges of mountains. To make the work still more difficult and unsatisfactory, Sir William was obliged to entrust it to men entirely without scientific training of any kind and ignorant of the simplest points in regard to geologic structure, more particularly when overturned strata or distortions, arising from the presence of intrusive masses, complicated the problem. But little attempt was made by his assistants to record strikes and dips, and, as the outcrops were frequently concealed by drift over long areas or terminated by thinning out or faulting, the joining of widely separated points, on the hypothesis that these represented portions of the same continuous band, of necessity produced a structure which was difficult to clearly comprehend.

Summary of Sir W. Logan's Laurentian Section.

The structure of the Laurentian deduced by Logan, largely from the labors of his assistants, and summed up in the statement given in Geology of Canada, 1863, known as the Trembling Mountain and Lake section, may be summarized as follows:

1.	The mass of orthoclase gneiss composing Trembling mountain, thickness unknown, estimated	5,000 feet.
2.	Crystalline limestone of Trembling lake	1,500 "
3–9.	Four other bands of orthoclase gneiss in masses of 1,580 to 4,000 feet, separated by bands of crystalline limestone, in thickness respectively from 20 feet to 2,500 feet, in all	15,750 "
10.	Anorthosite, into which the upper band of orthoclase gneiss was supposed to pass, thickness entirely conjectural	10,000 "
	The whole supposed to present an ascending series and aggregating	32,250 "

Recent Investigations necessitate Change in the Section.

Within the last forty years the settlement and opening up of this country has gone forward at a comparatively rapid rate. Great areas have been cleared, and roads penetrate the townships in all directions and extend northward along the principal rivers for over one hundred miles, so that cross-sections are readily afforded and areas easily studied, concerning which thirty or forty years ago the information was merely conjectural; from the work of late years, therefore, it has been found necessary to make very important changes in the section, as just stated.

The Anorthosite Masses north of Saint Jerome.

In the eastern portion the study of the anorthosite masses north of Saint Jerome by Dr F. D. Adams has conclusively shown that these are of intrusive origin, since in many places they cut directly across the strike of both the gneiss and limestone, while in others they have come to the surface in long dike-like bands along the lines of sedimentation of the gneiss. With the anorthosite proper are sometimes associated, more particularly along the lines of contact with the gneiss, zones of gabbro rock, while pegmatization is frequently seen in the former as we approach the junction.

Trembling Mountain Section Re-examined.

A careful reëxamination of the Trembling Mountain section westward to the Iroquois chute on the Rouge river, and which was formerly regarded as an ascending one, shows that this view cannot be maintained. In this space no less than three anticlinals with their corresponding synclinals occur, while the section is further complicated by faults of very considerable extent. Of the bands of limestone said to occur there, only one, namely, that of Trembling lake, was found, and this band, instead of occurring as an interstratified portion of the orthoclase-gneiss series, presents the form of a synclinal with converging dips in the underlying gneiss both on the east and west sides of the lake, the western flank of the Trembling mountain, which comes down to the east shore of the lake, having a regular dip to the northwest of 60°, upon which the limestone is seen to rest and to form part of a small island in the lake, while on the west side of the lake great hills of gneiss, similar to that of Trembling mountain, occur and show a southeast dip toward the water of from 40° to 90°. The limestone itself, which from its position forms the lowest calcareous member given in the original section, shows first at the discharge of the lake from the south end in a band exposed for

about fifty feet. It appears also in several small islands near the center and northern half of the lake, where it has at one place a breadth of about 75 feet. In its northern part this band changes its course from a nearly north direction to one nearly at right angles to it, and appears to be abruptly terminated against the bold walls of gneiss which extend along the west shore of the lake. The remaining part of the section crossing Great Beaver, Long and Green lakes shows no limestone in any portion, with the exception of a small outcrop from two to three feet in thickness, of impure character, associated with gray and rusty gneiss on a small island near the north end of Long lake. The timber along the shores of this lake being recently burnt off, a succession of ledges of red-gray gneiss of the usual aspect is disclosed, which here have a general dip to the west, the reverse dip to the east being clearly seen in the gneiss ridges which extend for some distance along the east side of the Rouge river below the Iroquois chute. It is but just to say that in the compilation of this section the notes of survey and of the geology as well were furnished by one of Sir William Logan's assistants, whose technical knowledge was limited and employed in making a topographic sketch of the area in question.

The thickness of the Trembling Lake band of limestone is difficult to estimate, but it is not apparently great, since, from the portions exposed, at no point is there more than fifty feet in vertical thickness seen. The area beneath the water is uncertain, and any attempt to estimate it in such a folded series of strata would be only conjectural.

Region between Anorthosite Area and Gatineau River.

In the region embraced between the Anorthosite area north of Saint Jerome on the east and the river Gatineau on the west, a distance of about eighty miles, several traverses have been made both by canoe along the lakes and rivers and by measurements along the roads which have been opened up in the country north of the Ottawa, and thus a very good opportunity has been presented of studying the structure in detail over a very considerable area. It will be observed that in all the reports, both of Logan and Murray, on the Laurentian the folded and sometimes overturned character of the strata is pointed out. The great resemblance in the character of the gneiss at the various horizons, supposed to be separated by the different limestone bands, and the great similarity in the bands of the limestone as well, is also frequently noted. A close examination of the limestone outcrop throughout the whole eighty miles of the section indicated has led us to the conclusion that in nearly every case the limestone bands occupy well-defined synclinals, which are separated by anticlinals in the underlying gneiss; that in

those cases where any considerable quantity of limestone appears to be overlaid by gneiss in regular sequence, such superposition of the gneiss is due to overturned strata, and that sometimes gneiss is brought against the calcareous measures by lines of fault. Abrupt changes of dip and strike are frequent, and in occasional sections, displayed along the shores of some of the larger inland lakes, the repetition of the folds into well-defined synclinals of limestone, separated by anticlinals of gneiss, occur for many hundreds of yards and reveal this feature of the structure very clearly.

Further, it has been found impossible to trace any particular band of limestone to any considerable distance continuously. Masses of limestone are often local in their development, presenting frequently lenticular forms which are thick near the center and thin off toward the extremities. They are often terminated abruptly by dislocations of the strata or by the intrusion of other rock masses, and frequently the synclinal structure in the gneiss can be seen for a long distance after the ending of the calcareous overlying portions which may have been removed by by denudation. In certain areas the synclinals follow one another in quick succession, while the limestone may be exposed for only a few hundred yards or feet in each. In many places also there is a very heavy covering of clay drift and sand, which conceals both the gneiss and limestone. The latter is rarely seen except in valleys, the hills where not of intrusive syenite or anorthosite being of the harder and more feldspathic variety of gneiss, often interlaced with intrusions of feldspathic rock or pyroxenic dikes.

While it is impossible to give in a paper of this kind such data as strikes and dips on which the theory of structure here presented rests, it may be here stated that throughout the section of eighty miles or more from east to west the limestone occupies the synclinals in the gneiss almost without exception. It will, however, be understood that in the lower part of the calcareous portion certain thin bands of limestone are interstratified with the grayish and rusty gneiss which forms the upper portion of the stratified gneiss series, and thus a gradual upward passage from the gneiss into the limestone is presented, but in no observed case are these interstratifications of gneiss of any great thickness, and their relations to the overlying calcareous beds can be easily recognized.

The Laurentian Gneiss and Limestone.

Their Thickness.—It is, of course, almost impossible to arrive at any correct conclusions as to the thickness of the gneiss or limestone in a series so twisted and so faulted as the Laurentian. Perhaps the best section for this purpose is found on the Rouge river from a point about

six miles above its mouth, along the road which follows down the east bank and alongside of which for several miles cliffs of grayish and reddish-gray gneiss extend.

The limestone does not appear on the east bank of the river, but the directly underlying rusty gneiss forms the upper member of the section here exposed, the calcareous portion showing in small ledges on the west side not far away. The series of gneisses have a general strike of N. 20° E. magnetic, the variation being about 12° west, and the dip is to the northwest at angles of 65° to 80°. The section is exposed for over two miles across the strike, as seen along the road, and in this distance no limestone appears, but in the southern extremity of the section, about two miles in rear of Calumet station, it shows in low-lying ledges near the top of the high hill at this place. Supposing that there is no break in this section, there would be at this place not far from 10,000 feet of continuous reddish and reddish-gray gneisses beneath the limestone. It is evident that such figures, however, cannot be taken as accurately stating the real thickness at this point, as faults and repetitions of strata may occur at several places.

Their stratigraphic Relation.—The rocks underlying the limestone in descending order, for we now assume the calcareous portion to form the summit of the Laurentian sedimentary and metamorphic series, may be thus stated:

Limestone in thin bands with interlaminations of rusty and grayish gneiss, the bands of limestone having a thickness from a few inches to several feet, the gneiss sometimes with a thickness of ten to fifty feet, shading downward into grayish and blackish gray, often garnetiferous gneiss, with certain portions of a reddish shade from the presence of red orthoclase. With these are often associated, more particularly in the upper part, beds of quartz rock or quartzite, which sometimes reaches a thickness of several hundred feet. The above are all found to be well stratified.

Reddish-gray gneiss, with the indications of stratification less easily seen and in places with foliation only. This underlies the well-banded gneiss of the upper part of the section, and in certain portions even the foliation becomes so obscure as to be indistinguishable except in large well-weathered masses.

Their physical Characteristics.—The limestone portion in its lowest part has numerous inclusions of the rusty gneiss, which have apparently been drawn out and twisted into long serpent-like forms, sometimes in bands of ten to fifteen feet in length; in other cases the inclusions are small and have more the appearance of pebbles. The limestone itself is frequently intensely crumpled, sometimes in minute crinklings;

in other places in large corrugations; but in the upper part of the mass these frequently disappear and the strike and dip can be readily seen. Occasionally the subjacent gneiss is crumpled in a similar manner, but this is not the case as a rule. In certain areas also the limestone mass contains well-rounded pebbles or masses of quartzose rock and grayish gneiss, presenting the aspect of a true conglomerate. This character can be well seen in a low cliff one mile and a half in rear of Calumet station, on the Canadian Pacific railway, as well as at many other points around the shore of the inland lakes, conclusively showing that this conglomerate is widely distributed.

Associated intrusive Rocks.

In addition to the gneiss and limestone, which may be regarded as forming the great mass of the Laurentian rocks, certain areas of intrusive rocks present features which are worthy of something more than a merely passing notice. Of these some are of large extent, as in the case of the anorthosite areas north of Saint Jerome and the syenite masses of Grenville and Chatham, while other masses, though not so conspicuous as these, are equally important as having exercised a marked influence upon the occurrence of the principal economic minerals of the district.

Of these no less than six, if not seven, clearly distinguishable periods of intrusion can be recognized. In addition to the large masses of anorthosite and syenite just referred to, presumably the large areas of augen-gneiss seen more particularly in the country adjoining the upper Rouge river belong to this class, since they have without doubt exercised a marked effect upon the strike and dip of the gneissic and calcareous rocks with which they are in contact. The masses of augen-gneiss present no trace of stratification and very rarely even of foliation.

Of smaller intrusions may be mentioned the great series of pyroxenic dikes which penetrate the gneiss of the phosphate district, and which are generally of some shade of green, and the quartz and feldspathic, generally white-weathering, dikes which are also prominent in the same area. Certain black, fine-grained trappean dikes are also frequent which cut both the preceding, some of which can be traced for many miles crossing the strike of both the gneiss and the limestone. In regard to the age of these trappean dikes it may be said that while they cut the limestone transversely they are cut off by the mass of the Grenville syenite.

In connection with this syenite also is a mass of intrusive porphyry, evidently from the mode of its occurrence of later date. Other smaller intrusions, but recognized at points over a very wide area, are of a very coarse, black hornblende rock, in which the hornblende is the chief

mineral constituent recognized. This rock resembles closely the black, coarse dikes which are found in connection with several of the intrusive mountains of the eastern townships.

Of the pyroxenic and feldspar dikes it may be said that in earlier reports they are described as integral portions of the gneiss formation. In places they extend along the lines of bedding, and are of the nature of bedded dikes, but in others they cut transversely across the strike of the gneiss, and their intrusive character is further established by the displacement and alteration of the strata in contact and by the formation of crystals of various kinds. The effect of the intrusion of the pyroxene upon the occurrence of economic minerals as well is easily seen at many of the apatite mines of the Buckingham district, and upon the establishment of their intrusive character the occurrence of the phosphate is more readily explained. It has been found by careful examination at many points that this apatite occurs, not in the gneiss itself, but in the mass of the intrusive pyroxene dikes; and, further, that its presence in workable quantity is always near the contact of the dike with the gneiss. Occasionally apatite is found in the limestone overlying, but only in detached crystals, along with pyroxene and mica and graphite. The same effect is visible in the occurrence of the mica and graphite, the workable deposits of which are either in the mass of the intrusive rock or in the gneiss and limestone adjacent.

Résumé and Conclusions.

Reviewing, then, briefly the conclusions as to structure arrived at by the writer, the succession, in ascending order, in the district under consideration, may be thus stated:

1. Reddish-gray gneiss without distinct signs of bedding or stratification, but with a foliated structure. In connection with this are great masses of syenite-gneiss and augen-gneiss, in which foliation is for the most part entirely wanting, and much of which is presumably intrusive.

2. Reddish orthoclase gneiss, interstratified with black hornblende, grayish quartzose and garnetiferous gneiss, with beds of grayish quartzite, and rusty gray, often highly quartzose, gneiss, the whole showing a well-stratified arrangement of beds, generally with very distinct appearance of sedimentation, many of the beds in the upper part having the aspect of regularly deposited layers of quartzose sandstone.

3. The grayish and rusty gneiss passes upward gradually into the calcareous portion of the system, thin bands of limestone first appearing as interstratified beds along with the gneiss, the interstratification becoming less as we ascend the scale, till, through scattered, twisted inclusions, the gneiss disappears and the rock becomes a regular crystalline limestone,

which forms the upper member of the Laurentian proper, at least east of the Ottawa river. West of that river, in the area north of Kingston, the section of the Archean may be completed upward thus:

4. A series of schistose rocks, highly metamorphic, comprising talcose, sericitic, chloritic and micaceous schists, described in earlier reports as the Hastings series. This overlies the crystalline limestone of the upper Laurentian and is believed to represent the lower member of the Huronian system. These schists are the exact lithologic equivalent of the Huronian rocks of the anticlinals of the eastern townships, as in Sutton mountain and elsewhere, and also of the lower part of the Huronian of New Brunswick. In both the last-named areas they are overlaid by more typically volcanic portions of the Huronian, such as the diorites, felsites, etc., and these in turn are succeeded upward by the conglomerates, quartzites and slates of the lower Cambrian.

Under the present arrangement of the Laurentian of Quebec the parallelism with the rocks of the system as displayed in southern New Brunswick is very close. Thus, according to the measurements of Messrs Bailey and Matthew, published in the Report of the Canadian Geological Survey for 1870–'71, the rocks of the system are there divided into a lower and an upper portion; the former comprising the usual variety of grayish and reddish-gray gneiss with syenitic and dioritic rocks, in all estimated at 2,500 feet, the latter consisting of dark-grayish and cream-colored dolomitic limestone with rusty grayish quartzose gneiss and quartzite capped by grayish limestone and black graphitic shales.

North of the Ottawa neither the Huronian rocks of the Hastings series nor the quartzites and other rocks of the lower Cambrian appear. A short distance below the city of Ottawa the gneiss and limestone of the upper Laurentian are overlaid by nearly flat-lying ledges of Potsdam sandstone, which passes upward gradually and conformably into the Calciferous limestone formation. North of Saint Jerome also a limited outlier of the lower Calciferous is seen to rest upon the Laurentian. Further down the Saint Lawrence toward the city of Quebec the formations resting directly upon the Laurentian are the Chazy and the Trenton, the same general horizontality of the measures being preserved, except where broken by lines of fault.

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HEIGHT OF THE BAY OF FUNDY COAST IN THE GLACIAL PERIOD RELATIVE TO SEA-LEVEL, AS EVIDENCED BY MARINE FOSSILS IN THE BOWLDER-CLAY AT SAINT JOHN, NEW BRUNSWICK*

BY ROBERT CHALMERS

(*Read before the Society December 29, 1892*)

CONTENTS

LOCALITY, AREA AND THICKNESS OF THE BOWLDER-CLAY DEPOSIT.

The occurrence of a thick deposit of bowlder-clay on the Bay of Fundy coast just west of Saint John harbor, containing intercalary seams of

*Published by permission of the Director of the Geological Survey of Canada.

stratified clay, was referred to in my report on the surface geology of southern New Brunswick.* This bowlder-clay forms a marginal strip of the land from Carleton to Duck cove, one and a half to two miles in length, and in the bank facing the sea rises from 40 to 60 feet in height above the beach. The part of it jutting out into the bay and forming a headland opposite Partridge island is called Negrotown point. A breakwater has been constructed there. The bowlder-clay at this point attains its greatest width, being 1,033 yards across in a north and south direction. At the Fern ledges, so called, from three-quarters of a mile to a mile west of the breakwater, it narrows to 215 yards, again widening out, however, before being overlapped at Duck cove, a little beyond, by fossiliferous *Leda* clay and *Saxicava* sands. At the Fern ledges the exposed thickness of the bowlder-clay, including the intercalary stratified seams, is by actual measurement 61½ feet, but its thickness decreases to the eastward.

Direction of Striæ on Rocks.

The ledges which come out on the shore from underneath the bowlder-clay here are well striated, the direction of the striæ being S. 2° W., S. 2° E., S. 10° E., S. 20° E., S. 30° E., S. 56° E., S. 60° E., and S. 65° E. (true meridian), and several of these courses appearing often on the same surface. The stoss-side is invariably to the north. These divergent striæ are noteworthy and indicate very clearly the action of several bodies of ice as they debouched into the sea.

To the east of the Fern ledges no rock exposures are seen along the shore, and the bottom of the bowlder-clay is covered up by beach sands and by the bowlders and débris which have fallen down as the bank is being eroded by the sea.

Topography of the District north of the Bowlder-clay Deposits.

Immediately to the north of this marginal belt of bowlder-clay and occupying the peninsula between the mouth of the Saint John river and the Bay of Fundy lies a group of hills from 175 to 225 feet high, known as Carleton heights. The rock surfaces on many of these are bare and exhibit their highly glaciated condition. The main courses of the striæ are S. 2° E. and S. 16° W. (true meridian).

The district around the mouth of the Saint John river has a hilly and broken surface, but the larger portion of it lies, nevertheless, below the 220-foot contour line. It is a locality which has been very favorably situated for the nourishment of glaciers. Accordingly we find here

*Ann. Rep. Geol. Surv. Canada, vol. iv, part N, 1888-'89.

abundant evidence of the former existence of land ice, and, from the position of the striæ and the character of the bowlder-clay, the conclusion that the ice which covered the district flowed out toward the open waters of the Bay of Fundy is beyond question.

The Bowlder-clay.

Source of the Materials composing it.—Field investigations reveal the fact that the materials composing the great mass of the bowlder-clay are obviously derived from the rocks lying immediately to the north. These rocks belong to the pre-Cambrian, Cambrian and Carboniferous Bowlders of these systems, consisting of granites, gneisses, Lower Carboniferous conglomerates, diorites or diabases, limestones, sandstones, slates, quartzites, etc., are displayed in the débris along the foot of the bank, strewn upon the beach, and also appear scattered throughout the mass of bowlder-clay. Many of them are large, the great majority being from 3 feet to 8 or 10 feet in diameter, and a considerable number are striated and polished. At Negrotown point the largest bowlders are of Lower Carboniferous conglomerate, the parent rock of which is from 3 to 10 miles to the north.

Clay and gravel, or rock débris, constitute the principal bulk of the bowlder-clay. The uppermost parts are less compacted than the lower and are capped by *Saxicava* sands in places. This renders it permeable by water to some depth, and, in those parts which contain stratified seams of clay, springs ooze out in the bank. Owing to this fact, and to the foot of the bank being continually eroded by the sea, landslips are of frequent occurrence and rapid denudation of the bowlder-clay is taking place.

Its stratified Portions.—The stratified portions of the bowlder-clay are for the most part thin, and form irregular, lenticular seams in the heart of the unstratified mass. They are distinctly laminated, and in some places, as at the Fern ledges, the strata dip slightly northward, that is, away from the shore. The material is a tough, dark red, brick-clay, containing a few pebbles and bowlders, scarcely any of which exceed 9 inches or a foot in diameter. These stratified bands usually occur in the middle of the bowlder-clay bank, being underlain and overlain by unstratified deposits, often of considerable thickness.

Section at the Fern Ledges.—The following section of the bowlder-clay at the Fern ledges will serve to illustrate its structure and character; it was carefully measured, in descending order, a few feet to the west of the section given in my report above cited:

1. Unstratified bowlder-clay, with three or more thin seams or layers of clay and sand interstratified therewith. It contains pebbles and bowlders of all sizes up to 9 inches or a foot in diameter, some of which are striated. The seams of clay and sand dip slightly northward or away from the sea. The uppermost parts contain a good deal of sand, and have apparently been worked over in the *Saxicava* sand period. The surface of the ground is strewn with bowlders from 2 feet in diameter downward; total thickness, 12.7 feet.

2. Typical, unstratified bowlder-clay, containing numerous glaciated bowlders and pebbles; bowlders from 3 to 5 and 6 feet in diameter are common; thickness, 25 feet.

3. Stratified, tough, dark-red clay, forming a wavy, lenticular seam, distinctly laminated, the strata dipping slightly northwestward, but irregular and uneven, and not occupying a continuous horizontal position, except very locally. To the west of the section it decreases in thickness and runs down to within a few feet of the bottom of the bank; to the east it first rises somewhat higher and then descends likewise, diminishing in thickness till only a foot or two of it can be seen. It contains a few pebbles, and occasionally a bowlder—one 10 inches in diameter was noticed. No fossils were detected in it; thickness in the thickest part, 14 feet.

4. Unstratified bowlder-clay, the same as number 2. Bowlders 3 to 6 feet in diameter are numerous. These are strewn along the foot of the bank as well as upon the beach. The total thickness of this bed is from 9 to 10 feet.

Following this bed (number 4) of bowlder-clay continuously westward from the line of the section we find it, at a distance of 15 paces, resting on the glaciated ledges. Here it is observed, however, to have only a thickness of from 3 to 5 feet. The stratified seam overlying it has, as stated above, also thinned out here, but is, nevertheless, well defined. Striated rocks, with this bed of bowlder-clay reposing on them, extend continuously along the shore for about 90 yards farther west. There is much variation in the direction of the striæ. Eight or more different courses of them occur on these ledges, varying from S. 2° W. to S. 65° E. (true meridian). These, it is evident, must all have been produced by the glaciers which laid down the bottom portion of the bowlder-clay (number 4 of the section); for before the ice which deposited the upper portions of the unstratified beds (numbers 2 and 1 of the section) could have striated the rocks it would have to work over the whole of the deposits beneath it, thus destroying all stratification therein and reducing them to a pell-mell mass.

Section at Negrotown Point.—This section was measured at a distance of about a quarter of a mile west of the Negrotown Point breakwater. In descending order the beds are as follows:

1. Typical bowlder-clay, unstratified, containing bowlders 2 to 5 feet in diameter, most of them glaciated. The total thickness of this bed is 11 feet.

2. An irregular, wavy, lenticular seam of stratified bowlder-clay, not in horizontal position, and varying in thickness from a few inches to a foot or more.

3. Bowlder-clay the same as number 1, and containing similar bowlders but apparently bedded in some parts. In this division of the bowlder-clay series the following species of marine shells were found: *Yoldia* (*Leda*) *arctica*, abundant and well preserved, often with the epidermis on; *Belanus crenatus* (fragments), *Saxicava rugosa*, *Mya arenaria* (a single valve), *Macoma calcarea*, *Nucula tenuis* (much broken), *Buccinum* sp. (?), probably *undatum* (a fragment), etc. All the species except *Yoldia* are quite rare. They appear to be indiscriminately scattered through the mass. Thickness of this part of the bowlder-clay, 6 to 10 feet.

4. Stratified, dark red, tough clay, distinctly laminated, with a few bowlders of the same kinds of rocks as those met with in the unstratified portions; the deposit irregular and wavy, not in a horizontal position and somewhat lenticular, or rather not maintaining the same thickness for any distance. Layers of this division of the series are seen sometimes to run up obliquely into and terminate in the unstratified bowlder-clay immediately above, and in other places apparently to graduate into it. Scattered throughout are shells of *Yoldia* (*Leda*) *arctica*, well preserved, often in the bottom with the valves closed and the epidermis intact; *Nucula tenuis* (broken), *Balanus crenatus* (fragments), *Saxicava rugosa*, *Macoma calcarea*, *Buccinum* and *Mya* (fragments), and one or two undetermined species. Thickness, 4 feet.

5. The height of the whole bank here being about 45 feet, there still remain 19 or 20 feet of it below the stratified fossiliferous portion, number 4. For the space of some hundred yards both east and west of the section, however, this lower part is concealed from view by landslides. Nevertheless, it is evident that a thick bed of bowlder-clay underlies the stratified seam, number 4; whether containing other stratified layers and fossils it is at present impossible to say. No rock outcrops are visible, nor is the bottom of the bowlder-clay in sight anywhere in the vicinity of Negrotown point. The glaciation of Partridge island, which is in Saint John harbor, about a mile distant from Negrotown point, was apparently accomplished by the ice which moved out from the mainland. The ice which produced a portion at least of the bottom bowlder-clay

must therefore have extended some distance beyond the present coast line; and from this fact the inference may be drawn that when it was deposited the land stood as high as at present relative to sea-level and perhaps higher.

Fossil marine Shells.

Their Occurrence in the Bowlder-clay at Negrotown Point.—The first discovery of marine shells in the bowlder clay at Negrotown point was made by W. J. Wilson,* my assistant, in 1891. Heavy storms during the previous winter, accompanied by very high tides, had eroded and undermined the bank to such an extent as to cause landslips, and also to clean off the falling débris from the face of the slope, thus affording fresh exposures. The locality was examined by Baron Gerard de Geer, of the Swedish Geological Survey, and on several occasions since by myself, and I now feel certain the shells in the stratified portion of the bowlder-clay at least are *in situ*, and lived in the sea along this coast during the glacial period, and were entombed in these clays when the land stood considerably lower than at present.

In regard to the shells found in the unstratified bowlder-clay, some of them may have been pushed out in the deposits from the littoral into deeper waters by land ice. The presence of *Mya arenaria* in these beds along with *Yoldia arctica*, etc, may thus be accounted for. The irregular line of contact between the stratified and unstratified beds, the gradual changing of one into the other along this line. the fact of curving, irregular strata running up diagonally into the overlying unstratified mass in many places, all tend, in my judgment, to show that the unstratified fossiliferous bowlder-clay has also been deposited in its present situation beneath the sea.

Their Occurrence in the Bowlder-clay of the Saint Lawrence Valley.—Marine shells have been found by Sir J. William Dawson in the bowlder-clay of the Saint Lawrence valley, at Isle Verte, Riviere du Loup, Murray bay and Saint Nicholas,† the species comprising *Leda truncata* of Brown, *Yoldia arctica* of Sars, *Balanus hameri* and *Bryozoa*, the two latter adhering to bowlders and large stones, "evidencing," as the author says, "that they had for some time quietly reposed in the sea bottom before they were buried in the clay."‡

* I have to acknowledge my indebtedness to W. J. Wilson, my assistant on the Geological Survey of Canada, for the collection of shells obtained from the bowlder-clay at Negrotown point, and for timely and valuable observations which his residence in Saint John enabled him to make.

† Notes on the post-Pliocene Geology of Canada: Can. Nat., 2d series, vol. vi, 1872, p. 25.

‡ Till or bowlder-clay containing an intercalary fossiliferous seam of clay occurs at Portland, Maine. Professor C. H. Hitchcock gives a section of it in Geology of New Hampshire, part iii, p. 279; but the fossils found in it do not seem to have been kept separate from those collected in other beds in that vicinity called Champlain, so that I am unable to correlate them with the fossils of the Saint John bowlder-clay.

Their Occurrence in the Drumlins near Boston.—Warren Upham and others have discovered marine shells and fragments of shells in the bowlder-clay hills called "drumlins" near Boston.* His list shows, however, that the species are nearly all the same as those of the recent period. Mr Upham explains the occurrence of these shells in the drumlins by supposing that the ice of the glacial period ploughed up certain marine beds inclosing them to the north and carried them forward to form a portion of the material of these bowlder-clay hills.

Their Occurrence in the Leda Clay and Saxicava Sands of New Brunswick.—Marine shells of Pleistocene age were found by G. F. Matthew and the writer a number of years ago in clays and sands on the coasts of the Bay of Fundy and Baie des Chaleurs, which have been correlated with the *Leda* clay and *Saxicava* sands of the Saint Lawrence valley. Lists of these shells were published in the reports of the Geological Survey of Canada, etc.† The height of the terraced deposits in which the shells occur clearly establishes the conclusion that when the lower fossiliferous portions were laid down the land stood from 180 to 220 feet lower than it is at the present day; and as the *Leda* clay and *Saxicava* sands containing these shells have invariably been found overlying the bowlder-clay, it is naturally inferred that their deposition began about the close of the glacial period and occupied a distinct and separate interval of Pleistocene time.

The Height of the Land and the Mode of Deposition of the Bowlder-clay.

It is a view generally held by glacialists who have studied the Pleistocene deposits and related phenomena of coast borders, especially within the glaciated belt, that the land was subsiding during the period of melting or retirement of the ice.‡ The lower unstratified portion of the bowlder-clay here was probably deposited during the greatest advance of the land-ice; this ice, as shown on a previous page, having extended beyond Partridge island. It seems to have consisted mainly of sheets flowing out from the Saint John and Kennebeckasis valleys which may

* Proceedings of the Boston Soc. of Nat. Hist., vol. xxvi, 1888.

† Report of Progress, Geol. Surv. Canada, part EE, 1877–'78; Ann. Rep. Geol. Surv. Canada, vol. 1, part GG, 1885.

‡ J. D. Dana, Am. Jour. Sci., third series, vol. ii, pp. 324–330; vol. v, pp. 198–211; vol. x, pp. 168–183, 409–438; vol. xxiv, pp. 98–104. J. W. Dawson, Bull. Geol. Soc. of America, vol. i, p. 318; Acadian Geology, supplementary note to fourth edition, 1891, p. 7. C. H. Hitchcock, Geology of New Hampshire, vol. iii, p. 279. Professor Hitchcock is, however, rather inclined to the view that it was the sea and not the land which changed level. Warren Upham, Bull. Geol. Soc. of America, vol. i, pp. 563–567. G. H. Stone, Am. Jour. Sci., vol. xl, pp. 122–144. Robert Chalmers, Ann. Rep. Geol. Surv. Canada, vol. iv, 1888–'89, pp. 10, 11*n*; Canadian Naturalist, vol. x, p. 54. G. M. Dawson, Report of Progess, Geol. Surv. Canada, 1877–'78, pp. 133–153 *b*.

have been confluent, but there were also glaciers from the adjacent valleys and from the hills in the vicinity of Saint John harbor. The divergent courses of striæ recorded in this paper indicate that the discharge of these into the depression of the Bay of Fundy was not strictly contemporaneous, but successive, for no single body of ice moving out into an open bay would, in my judgment, be likely to produce striæ diverging 65° to 67° apart, even with the land more elevated than it now is. Moreover, independent of the striation of this particular locality, we have in the eastern provinces of Canada very good evidence of the existence and diverse movements of local glaciers throughout the whole glacial period.* What the height of the coast district was at the time this lower bowlder-clay was thrown down, however, cannot be determined with any degree of accuracy. In the later Tertiary it was 200 feet or more above the level at which it now stands relative to the sea.† It may be stated that not only Partridge island, but the islands of Campobello and Grand Manan, lying off the mouth of the Saint Croix river, have been overridden by the land-ice. The latter is now separated from the mainland by a strait or passage 45 to 50 fathoms deep and from 8 to 9 miles wide.‡ Ice of such a comparatively local character as has been shown to have occupied the eastern provinces of Canada in the Pleistocene § could not, it seems to me, reach Grand Manan unless the land were higher relative to the sea than at present.

But whatever views may be entertained regarding the height of the land when the lower bowlder-clay referred to was deposited, the upper or overlying glacial deposits, stratified and unstratified, were evidently laid down when the subsidence of the land was in progress and had perhaps reached its maximum. The stratified fossiliferous portion, from its position and height above sea-level and the well-preserved condition of a number of its contained fossils, unequivocally proves that the coast must have then been from 100 to 200 feet lower than it now is. The retirement of the ice at this time, whether caused by the subsidence and consequent breaking away of its margin or by an amelioration of the climate, or by both, does not seem to have been more than local, this supposition being at least sufficient to afford an explanation of all the facts. The irregular lenticular condition of the stratified portions and the fact of tongues of these being interstratified with the overlying unstratified bowlder-clay indicate with tolerable certainty that they must have been deposited as we now find them along or near the ice-front.

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*Glaciation of Eastern Canada. R. Chalmers, Canadian Record of Science. Montreal, April, 1889. Ann. Rep. Geol. Surv. Canada, 1885 to 1889.

†Ann. Rep. Geol. Surv. Canada, vol. iv, 1888–'89, pp. 8, 9 *n*.

‡Ann. Rep. Geol. Surv. Canada, vol. iv, 1888–'89, pp. 48, 49 *n*.

§R. Chalmers, Ann. Reports Geol. Surv. Canada, 1885 to 1889. Trans. Roy. Soc. of Canada, 1886, sec. 4, art. 10. Canadian Record of Science, April, 1889, pp. 319-333.

Oscillations of the Ice-margin.

It is abundantly clear that there have been several oscillations of the ice-margin. Not only do the stratified seams and irregular, roughly horizontal breaks in places in the upper portion of the bowlder-clay show such advances and recessions of the ice, but the divergent courses of striæ likewise denote several ice-movements as stated and indicate that the bottom portion of the bowlder-clay has been formed by a number of successive accretions or additions of material. The whole of the bowlder-clay in question would seem, indeed, to have been produced in a zone of oscillation of the ice-front, the ice retiring to and advancing from the Carleton and other hills to the north. The later advances were comparatively light, otherwise the older or first-formed beds would have been ploughed up much more deeply than they are. This may, however, be partly due to the continued subsidence, which at the close of the glacial or commencement of the *Leda*-clay period amounted to 220 feet below the present high-tide level, in which case these deposits may really have been thrown down in a sea of considerable depth.

Climatic Conditions during Deposition of the *Leda* Clay and *Saxicava* Sands.

The deposition of the *Leda* clay closely followed the last recession of the ice and may, indeed, have been in progress before it finally disappeared from the hills around the mouth of the Saint John. The *Leda*-clay fauna here does not denote such arctic conditions as prevailed in the latter part of the glacial period, nor, indeed, in the *Leda*-clay period in the gulf of Saint Lawrence. This has been shown by G. F. Matthew and by Sir J. William Dawson.* The amelioration of climate following the retreat of the ice was coincident with a rising of the land, as indicated by the facies of the marine fauna found in the clays deposited in the quieter bottoms and of that of the sands, etc, in the shallower sea margins during the *Leda*-clay and *Saxicava*-sand period. No glacial deposits are known to overlie these, or be interstratified with them, on the Atlantic coast of Canada.

Conclusions.

The conclusions drawn from the foregoing facts may therefore be thus briefly summarized:

1. The bowlder-clay here described was deposited at or near the margin of the land ice which flowed out from the Saint John and Kennebeckasis

* Notes on the post-Pliocene Mollusca of Acadia: G. F. Matthew, Canadian Naturalist, vol. viii. Supplement to the 2d ed. of Acadian Geology, 1878.

valleys, etc. The ice-front was beneath the sea at the time the stratified and overlying, unstratified fossiliferous portions were deposited. These testify very clearly to several local oscillations of the ice-front and show unmistakably that this portion of the series was formed by a number of successive increments or additions of material, appearing, indeed, just as if the ice had "dumped" it a number of times in succession over the Carleton hills into the Pleistocene sea with little or no disturbance of the preëxisting beds.

2. The shells in the stratified portions of the bowlder-clay are *in situ*, and have been entombed in it in a sea 100 to 200 feet or more in depth. They are in too perfect a condition to have been transported in bowlder-clay by ice, and, moreover, the state of the beds in which they occur is opposed to this view. Those found in the overlying, unstratified bowlder-clay may have had the shallow-water species now found buried in it pushed out from the Pleistocene shore and thus mingled with the deep-water forms. All the species denote an arctic or a subarctic climate and a sea even colder than existed at the beginning of the *Leda*-clay period.

3. The land on this part of the Bay of Fundy coast during the deposition of this fossiliferous bowlder-clay must have been, therefore, 100 to 200 feet or more lower than at the present day, relative to the sea.

4. As the striæ on the rocks underneath the bowlder-clay indicate several ice movements varying in direction from S. 2° W. to S. 65° E., these and the formation of the lower bowlder-clay cannot all be due to one body of ice. The latter is therefore the product of several glaciers, each successive one having worked over all the material beneath it down to the rock surface.

DISCUSSION.

Mr WARREN UPHAM: The occurrence of *Yoldia arctica* as the only plentiful species in the intercalated stratified seams of clay met with in the bowlder-clay at Saint John implies that the margin of the ice was near when it inhabited the Bay of Fundy waters. This shell is now found living only in the Arctic ocean, and thrives most, according to Baron de Geer, in Spitzbergen, near the mouths of streams discharged from glaciers and muddy with the fine silt due to their erosion.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 4, PP. 371-458, FRONTISPIECE   SEPTEMBER 23, 1893

PROCEEDINGS OF THE FIFTH ANNUAL MEETING, HELD AT OTTAWA, CANADA, DECEMBER 28, 29 AND 30, 1892

HERMAN LEROY FAIRCHILD, *Secretary*

CONTENTS

Session of Wednesday, December 28

The Society met in the railway committee-room of the House of Commons. President G. K. Gilbert presided during the several sessions of the meeting.

At 10.20 a m the President called the Society to order and after a word of salutation introduced His Excellency, the Governor-General of Canada, Sir Frederick Arthur Stanley, who extended a hearty welcome to the Fellows of the Society. Science, he said, was cosmopolitan and did not admit of distinctions of race, creed or national boundary; as far as science was concerned, all were one brotherhood. He assured the visitors that they would be shown every hospitality while in the city. The President made reply to the welcome of His Excellency, referring in complimentary terms to Canadian hospitality.

The Council report was read by the Secretary as follows:

REPORT OF THE COUNCIL

To the Fellows of the Geological Society of America,
in Fifth Annual Meeting, 1892:

Meetings of the Council.—During the past year the Council has held two meetings, coincident with the meetings of the Society, each with four sessions. A large amount of administrative business has been done, with earnestness and unity.

Meetings of the Society.—The records of the two meetings held during the year, at Columbus and Rochester, will be found in full in the printed proceedings of the Bulletin.

The attendance has been small, at Columbus twenty-three and at Rochester thirty-four. The prosperity and success of the Society is, however, not dependent upon the size of its meetings. The brief experience would seem to indicate that a larger attendance would be secured at the great cities of the east, but as an international society it would not be proper to localize its sessions for the sake of larger meetings.

Membership.—The Society has lost three Fellows during the year by death: Dr J. S. Newberry, Dr T. Sterry Hunt and Professor J. H. Chapin. Four names have been dropped, by application of the rules, for non-payment of dues. The latest printed roll of membership bears the names of 209 living and 9 deceased Fellows. At the summer meeting 13 men were elected, of whom 12 have qualified, namely: A. E. Barlow, H. P. H. Brumell, M. R. Campbell, A. del Castillo, H. W. Fairbanks, L. S. Griswold, A. P. Low, V. F. Marsters, W. B Scott, C. H. Smyth, Jr.,

J. Stanley-Brown, C. L. Whittle. From the list will be taken one name by resignation and one for delinquency, leaving a total fellowship of 219. Three elections are announced at this meeting: Professor H. F. Reid, Mr. F. W. Sardeson and Mr J. F. Whiteaves.

Nine nominations are before the Council.

After long and serious consideration the Council has determined not to present any names for Correspondents at the present time.

Bulletin Publication.—Volume 3 has been distributed to all Fellows, subscribers and exchanges direct from the Secretary's office. The cost of the volume is given later in this report. The proceedings of the summer meeting, making the first two brochures of volume 4, are almost ready for distribution.

Bulletin Distribution.—The following tables show the distribution of the three volumes. In explanation it should be said that the edition of volume 1 was only five hundred copies, and that the first two volumes were sent to the Fellows directly from the printers; also that the stock of volume 3 has not been wholly unpacked. It is found more convenient to make the tables cover the whole distribution from the Secretary's office during the past two years. A comparison of last year's report with this will give the details for the past year.

Bulletin Distribution from the Secretary's Office During 1891 and 1892

BY COMPLETE VOLUMES

	Vol. 1.	Vol. 2.	Vol. 3.
In reserve	102	346	395(?)
Donated to institutions ("exchanges")	81	81	81
Held for "exchanges"	10	10	10
Sold to Libraries, etc.	54	55	53
Sold to Fellows	11	9	
Sent to Fellows to supply deficiencies	2	1	
Donated by Council	3	3	1
Bound for office use	1	1	1
Sent to Fellows in brochures, as issued			209
Number of complete copies received	264	506	750(?)

BY BROCHURES

		Vol. 1.	Vol. 2.	Vol. 3.
Sent to Fellows to supply deficiencies	to 8 Fellows	39		
	to 29 Fellows		90	
	to 7 Fellows			13
Sold to Fellows		5	3	
Sold to the public		2		4
	(to 9 persons)		17	

Bulletin Sales.—As announced by the Secretary, in January, a circular letter advertising the Bulletin was sent to several hundred libraries in the United States and Canada. Subscriptions have been received from about thirty libraries, and a large number of irregular sales effected. A set of books kept by the Secretary shows the details. The financial result is given in the following tables:

Receipts from sale of Bulletin during 1892

BY SALE OF COMPLETE VOLUMES

	Vol. 1.	Vol. 2.	Vol. 3.	Total.	
From Fellows	$14 50	$19 00	$4 50	$38 00	
From libraries, etc.	170 00	175 00	142 00	487 00	
Total	$184 50	$194 00	$146 50	$525 00	
By last report (1891)	115 10	102 50		217 60	
Second total	$299 60	$296 50	$146 50		$742 60

BY SALE OF BROCHURES

	Vol. 1.	Vol. 2.	Vol. 3.	Total.	
From Fellows		$0 50		$0 50	
From the public	$1 40	60	$2 65	4 65	
Total	$1 40	$1 10	$2 65	$5 15	
By last report (1891)	3 15	4 95		8 10	
Second total	$4 55	$6 05	$2 65		$13 25

Grand total	$755 85
Received for volume 4, in advance	15 00
Receipts to date	$770 85
Amount uncollected	170 45
Bulletin sales to date	$941 30

"*Exchanges.*"—The list of institutions to which the Bulletin is donated is not materially different from that of the last report. Seventy-nine institutions have been placed on the list.

Library.—The material received in return for the Bulletin, mostly from foreign societies, makes about 100 volumes, entire or fractional. This is chiefly geological matter and should be useful to the Fellows as soon as it can be made accessible. The Council has not yet acted under the

authority conferred at the last annual meeting, empowering it to select a depository for this accumulating material, but the matter is in the hands of a committee and such selection will probably soon be made.

The matter collected by Professor Hitchcock is as follows:

A complete set of the Reports of the Second Geological Survey of Pennsylvania, 115 volumes and several elephant folio atlases.

Reports of the Geological Surveys of other States as follows: Illinois, 8 volumes; Ohio, 8 volumes; Arkansas, 7 volumes; Texas, 2 volumes; California, 9 volumes and pamphlets.

Tenth Annual Report of the U. S. Geological Survey, and Bulletins 62–81.

Miscellaneous books, 15; pamphlets, 225, largely authors' copies, especially of the younger Fellows. Several lists of publications of individual Fellows.

A few volumes from exchanges, and about 30 duplicates.

The number of contributors, 36.

Photographs of 35 Fellows.

Two large maps of the United States, made for the Society. Crayon portrait of Alexander Winchell.

Finances.—Following is a summary of the finances of the past year, the details being given in the Treasurer's Report:

Receipts from all sources, $3,010.52, made up of the following items:

Fellowship fees	$2,180 00	
Life commutations	100 00	
Interest and investments	102 73	
Sales of Bulletin	426 85	
Repayments on cost of Bulletin	200 94	
	3,010 52	
Balance from former Treasurer	1,258 95	
Total		$4,269 47

EXPENDITURES DURING THE YEAR

Publication of Bulletin	$1,667 68	
Maps and photographs	43 83	
Administration (including Bulletin distribution)	467 91	
Investments	1,488 90	
Total	$3,668 32	
Balance in Treasury	601 15	
		$4,269 47

The cost of volumes 1, 2 and 3 of the Bulletin is shown in the following tabulation:

COST OF BULLETIN

	Vol. 1. (pp. 593; pl. 13.)		Vol. 2. (pp. 662; pl. 23.)		Vol. 3. (pp. 541; pl. 17.)	
Cost to the Society:						
Letter-press......	$1,367 77		$1,935 27		$1,439 00	
Illustrations.....	291 85		302 35		261 60	
Total.........		$1,659 62		$2,237 62		$1,700 60
Cost to authors:*						
Letter-press......					$79 59	
Illustrations.....			$161 30		121 75	
Corrections......	$38 00		27 25		5 00	
Brochure covers..	68 00		30 00		12 00	
Total.........		$106 00		$218 55		$218 34
Aggregate.....		$1,765 62		$2,456 17		$1,918 94

Respectfully submitted,

THE COUNCIL.

The Treasurer, I. C. White, read his annual report, as follows:

REPORT OF THE TREASURER

Report of the Treasurer of the Geological Society of America for the Year ending November 30, 1892

The Treasurer, in submitting his financial report, would recommend that the By-laws of the Society be amended so that the Life Commutations shall go immediately into the Publication Fund. This would simplify the accounts and save the Treasurer considerable unnecessary work.

The detailed operations of the Treasury are shown by the following financial statement to December 1, 1892:

* Including, for volume 3, donations of printing and engraving by I. C. White, $111.09, and engraving by N. H. Winchell, $9.00; an aggregate of $120.09.

Balance-sheet.

RECEIPTS.

Cash, balance received from H. S. Williams, former Treasurer		$1,258 95
Fellowship fees for 1890 (1)	$10 00	
" " 1891 (16)	160 00	
" " 1892 (186)	1,860 00	
" " 1893 (1)	10 00	
		2,040 00
Initiation fees (14)		140 00
Life commutations (E. O. Hovey)		100 00
Interest on investments:		
On bonds of Tioga township, Kansas, February 1, 1892	$35 00	
On the same, July 30, 1892	35 00	
On Cosmos Club bonds, July 30, 1892	22 50	
On bank deposit, November 30, 1892	10 23	
		102 73
Sales of Bulletin		426 85
Repayment by Fellows of partial cost of illustrations, &c.:		
A. Winslow	$3 00	
I. C. White	99 09	
C. H. Hitchcock	8 60	
Robert Hay	35 00	
T. Nelson Dale	5 00	
W. H. Hobbs	15 00	
C. W. Hall and F. W. Sardeson	12 75	
J. E. Wolff	3 00	
A. H. Cole	19 50	
		200 94
Total		$4,269 47

EXPENDITURES.

Expenses of administration.		
Treasurer's office:		
I. C. White	$25 85	
Secretary's office:		
H. L. Fairchild	299 36	
J. P. Smith Printing Co.	68 95	
Raynor & Martin	24 00	
Rochester Printing Co.	49 75	
		$467 91
Maps and photographs:		
J. S. Diller	$9 83	
D. W. Sill	34 00	
		43 83
Publication of Bulletin.		
Editor's office:		
W J McGee	$55 24	
Printing:		
Judd & Detweiler	1,250 09	
Engraving:		
Moss Eng. Co.	314 05	
Photo-Eng. Co.	33 30	
J. L. Ridgway	15 00	
		1,667 68
Investment account.		
Bond Purchases and Deposits:		
8 Cosmos Club bonds	$800 00	
1 Cosmos Club bond and accrued interest	100 35	
Bank deposit	503 05	
" "	85 50	
		1,488 90
Cash, balance November 30, 1892		601 15
Total		$4,269 47

The Society elected as a committee to audit the Treasurer's accounts Robert Bell and R. D. Salisbury.

ELECTION OF OFFICERS FOR 1893

The result of the balloting for officers for 1893, as canvassed by the Council, was declared as follows:

President:

Sir J. William Dawson, Montreal, Canada.

First Vice-president:

T. C. Chamberlin, Chicago, Ill.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

No candidate for the offices of Second Vice-president, Councillors and Editor having a majority of all the ballots cast, the election of such officers under the rules was made by ballot, in the meeting, from the two candidates having the greatest number of votes for the respective offices. The President named as tellers for the balloting F. D. Adams and R. W. Ells. The balloting was separately for each office, and resulted as follows:

Second Vice-president:

J. J. Stevenson, New York city.

Councillors:

E. A. Smith, Tuscaloosa, Ala.
C. D. Walcott, Washington, D. C.

Editor:

J. Stanley-Brown, Washington, D. C.

ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was declared as follows:

FELLOWS ELECTED

Harry Fielding Reid, Ph. D., Cleveland, Ohio, Professor of Physics in Case School of Applied Science.

Frederick William Sardeson, Minneapolis, Minnesota, Post-graduate in Geology. Now engaged in paleozoic paleontology.

Joseph Frederick Whiteaves, Ottawa, Canada. Paleontologist and Assistant Director of the Geological Survey of Canada. Working on Canadian paleontology.

A memorial of T. Sterry Hunt, in the absence of the author, was read by C. R. Van Hise.

MEMORIAL OF THOMAS STERRY HUNT

BY RAPHAEL PUMPELLY

Thomas Sterry Hunt was born in Norwich, Connecticut, September 5, 1826, and died in New York February 12, 1892. His intimate friend, James Douglass, has drawn with a loving hand a sketch of his life, from which I have taken freely the details of his early years.* He came of Puritan stock, including on his mother's side the mystic Peter Sterry and the preacher, Thomas Sterry, author of a notable tract, "The Rot among the Bishops," in 1667, in England, and Consider and John Sterry, mathematicians in New England. For a short period only he attended the public school, and then, to aid in the support of his widowed mother and her family, he worked successively, a few months in each, in a printing office, an apothecary's shop, and a bookstore, and later in a country store. Bent on studying medicine, he kept a skeleton and home-made chemical apparatus under the counter, using the stove for a furnace. Mr Douglas says that with this equipment he made investigations into the properties of hydriodic acid, anticipating to a certain extent those of Deville. During a trip to New Haven, in 1845, at the meeting of the Association of Naturalists and Geologists he acted as reporter for a New York paper. Here he attracted the attention of the elder Silliman, who facilitated his admission into Yale, made him his assistant in water analyses, and took him into his household. This was the great turning point of his life and doubtless determined his chemical and mineralogical career. Under happy auspices while at Yale, between his eighteenth and twentieth year, he contributed eighteen papers to Silliman's Journal and wrote the Organic Chemistry for Silliman's First Principles.

At twenty years of age, in 1847, he became Chemist and Mineralogist to the Geological Survey of Canada, a connection which he retained till 1872. The Canadian Survey had largely to do with a great development of crystalline rocks, and with varied mineral resources. Hunt threw his energies into the work before him and, single-handed, worked out the

* Trans. Amer. Inst. Min. Eng., 1892.

chemical and mineralogical details of the economic geology of a vast region, and supplied to a great extent the lithological basis for a classification of its rocks. At the same time he was developing a system of chemic geology based very largely on his own original investigations. Logan and Hunt soon supplemented each the other—the one an excellent geologist, with a wide and growing field experience; the other an able chemist and mineralogist, with a versatile and suggestive mind. Both profited by this combination, which contributed greatly to the successful prosecution of the Survey. During this period he also occupied the chair of chemistry at the Laval University, at Quebec, from 1856 to 1862 and at McGill University, Montreal, from 1862 to 1868.

From 1872 to 1878 he was Professor of Geology at the Massachusetts Institute of Technology. He was a juror at the Paris Expositions in 1856 and 1857, and there came into personal contact with the geologists of England and the continent. In 1859 he was elected a Fellow of the Royal Society of London, and a member of the National Academy of Sciences in 1873. In 1881 the University of Cambridge conferred on him the degree of LL. D. He was acting President of the American Association for the Advancement of Science in 1871, President in 1877 of the Institute of Mining Engineers, and the first elected President of the Royal Society of Canada. It is to his motion, made to the American Association for the Advancement of Science in 1876, that we owe the plan for an International Geological Congress, and he held office at several of the meetings of this body. In 1855 the French government made him a Chevalier of the Legion of Honor, and later an officer of the same order, and after the Bologna meeting of the Geological Congress he received the order of Saint Mauritius and of Saint Lazarus.

Dr Hunt was a most indefatigable worker and reader of a wide range of literature, and seems to have had a wonderfully retentive memory. In speaking, his addresses and papers were given without notes and were remarkable for their ready fluency and directness of diction, as well as for logical arrangement of ideas. The number of his published contributions to scientific literature is very large, but the more important part of his work is embodied in the few volumes which he published: "Chemical and Geological Essays," 1874 and 1878; "Azoic Rocks," 1878; "Mineral Physiology and Physiography," 1886; "A New Basis for Chemistry," 1887, and "Mineralogy according to a Natural System," 1891.

Mr Douglas informs us that Dr Hunt was a good mathematician and had an excellent acquaintance with botany, in which his interest lay more, however, on the æsthetic and economic than on the purely systematic side. He acquired such a knowledge of French as enabled him to speak it equally fluently with English. Indeed, he was a remarkable

instance of self-developed genius, for he had a brief and imperfect public-school education and less than two years in Yale, where most of his time must have been spent in work as an assistant.

It is as an honored member of our Society and as a geologist that we have to speak of him on this occasion, and it is therefore fitting that we dwell particularly on those of his contributions to geology which mark his position in the history of the science and which also explain his individual attitude toward some of its more important problems.

His work in mineral chemistry and in the analyses of rocks led him naturally to the lithological side of geology. The logical and speculative nature of his mind impelled him to attempt the discovery of a general law underlying the origin of the crystalline rocks, both massive and schistose. He began in 1858 with the conception of a solid incandescent globe, which, at least in the outer layer, was an undifferentiated quartzless basic silicate, approximating dolorite in composition. At this starting point, while this mass contained all the non-volatile elements, the atmosphere still contained all the volatile elements, being densely charged with all the carbon, sulphur and chlorine, combined with oxygen or hydrogen, and containing watery vapor, nitrogen and a probable excess of oxygen. He considered that in the condensation of this atmosphere and the reaction of its powerful solvents upon the undifferentiated basic rock lay the key to the genesis of the crystalline rocks. The sulphur and chlorine of the condensing atmosphere combined with the protoxide bases of the rock and went to form the sulphates and chlorides of the ocean and to neutralize its waters. In the waters permeating the rock heated from below an active circulation was established, thus bringing to the surface the matters to be deposited.

Through this upward lixiviation the primary undifferentiated rock was separated into an upper acidic layer, chiefly of acid silicates, as feldspars with quartz, and a lower residuary basic and insoluble mass charged with iron and magnesium, the two representing the overlying granitic and the underlying basaltic layers required by many geologists. To this explanation he gave the name of Crenitic Hypothesis In the shrinkage of the great thickness, made porous by the lixiviation, he found the cause of the corrugation of the crystalline rocks and of the accompanying early extravasation of basic rocks. The lixiviation or crenitic portion of this hypothesis was not announced till 1884. In its earlier stages its author conceived the primal undifferentiated rock of the early globe to be everywhere deeply buried under its ruins—under a great thickness of fine and coarse sediments produced by the first decomposition of the rock by acid waters and by extensive subaërial decay, permeated by infiltrating waters and heated from below. Through the

circulation of these waters he imagined these detrital accumulations to have been differentiated into two great divisions, the one having an excess of silica, a predominance of potash and small amounts of lime, magnesia and soda, represented by the granites and trachytes; the other, having less silica and potash, and prevalence of soda, lime and magnesia, giving rise to pyroxene and triclinic feldspars. In the metamorphism and displacement of these differentiated sediments he explained the origin of the plutonic rocks. At this period he was a believer in the metamorphic origin of the crystalline rocks, holding with Keferstein "that all the unstratified rocks from granite to lava are products of the transformation of sedimentary strata, in part very recent." But the intimate relation, required by his growing hypothesis, between this metamorphism and the chemical processes acting upon a recently solidified globe, seem to have soon caused him to reject the possibility of the formation of crystalline rocks by metamorphic processes acting upon sediments of later than pre-Cambrian age; for, in the final formulation of the crenitic hypothesis, he states that the products of subaërial decay (both of the crenitic rocks and of the basic rocks erupted from the underlying residual primary basic mass), reacted upon by the materials brought up by the crenitic processes, contributed to the formation of the transition crystalline schist, and in the transition or pre-Cambrian schists he saw only the relatively feeble and dying-out action of the crenitic processes.

It was a natural consequence of this attitude that Dr Hunt took an active part in the "Taconic Controversy" and ranged himself on the side which claimed a pre-Cambrian age for the quartzite limestone and schist series of the great Appalachian valley called Lower Taconic by Emmons and Taconian by Hunt. He had thought out a system which premises that "the laws which have presided over the differentiation of the primeval chaos and produced the various groups of rocks, * * * which have determined the progressive changes in chemical constitution from the anti-gneissic granite down to the youngest crystalline schists and the detrital sediments of later times, are * * * not less certain and definite than those which preside over astronomical and biological development." He insists that "the great successive groups of stratiform crystalline rocks mark necessary stages in the mineralogical evolution of the planet."

Acting upon this idea, he divided the crystalline-rock-making time into six periods:

I. Laurentian—granite and gneiss—during which the lixiviating process brought up acid silicates and quartz; the presence of limestones in supposed Laurentian rocks being due to a reaction of the crenitic lime silicates.

II. Norian, the formation of which was only possible after the crenitic lixiviation had exhausted a large part of the accessible primary mass of much of its silica in the forms of orthoclase albite and quartz, so that the succeeding secretions furnished the less acid silicates, as labradorite and andesite.

III. Arvonian; a stratified series of rocks including petrosilex, and quartziferous porphyry associated with beds of quartzite, micaceous schists, great beds of hematite and more rarely layers of crystalline limestone. This series he places between the Laurentian and the Huronian, stating that he is unable to fix its exact relation to the Norian.

IV. Huronian.—The shrinkage originating in the removal from the primary mass of the material to form the preceding three series caused eruptions from the underlying basic mass, so that extensive areas, both of the crenitic acid rocks and of the eruptive basic rocks, were exposed to subaërial decay.

In this decay the acid crenitic rocks gave up their alkalies, leaving residual clays, while the basic rocks yielded their lime and magnesia. The alkaline and magnesian carbonates introduced a new factor into the history of the rocks, for, reacting upon the calcium-chloride of the primeval sea, this produced lime, carbonate and alkaline and magnesian chlorides. Thus a magnesian sea was formed. The reaction of the magnesian salts of this sea upon the petrolitic matters (lime silicates) of the continued crenitic secretions brought into the sediments a vast amount of magnesian silicates, giving a distinctive character and color to the resulting schists.

V. Montalban.—The Huronian required for its formation a magnesian sea caused by the subaërial decay of both crenitic and especially of eruptive basic rocks on one hand, and by the continued addition of crenitic lime-silicate secretions contributed in an advanced stage of lixiviation on the other. The building up of the Montalban series of fine-grained gneisses, granulites, mica-schists and schists abounding in aluminous silicates of the Andalusite type presupposes the comparative absence of magnesium from the seas. Here the gneisses are of purely crenitic origin, and the schists are derived mainly from the products of subaërial decay of the older crenitic rocks, the resulting clays, still carrying a portion of their alkali, with or without the aid of crenitic secretions, yielded by diagenesis, muscovite, quartz and the simple aluminous silicates.

VI. Taconian.—This great series of quartzites, limestones, hydromica-schists and argillites, according to Dr Hunt, marks a stage of diminished energy in the process. In the schists he sees apparently the products

of subaërial decay of the older crenitic rocks subjected to diagenesis, and in the presence of certain "apparently feldspathic matters forming imperfect gneisses" evidence of the still, though feebly acting, crenitic process. Traces of the still later and more feeble remnant of the crenitic process are found by Dr Hunt in the presence of rutile, tourmaline and staurolite and in the paleozoic argillites.

Having stated this order of development as an inflexible law, he assigned all the rocks generally called plutonic and metamorphic, respectively to these periods, thus forming an interdependent chronologic and lithologic canon. In this light it is easy to understand his reasons for denying the formation of crystalline schists during later periods than the pre-Cambrian, and also for rejecting a recognition of those processes which, like pseudo morphism, metasomatosis, etc, have been used in explaining local and regional metamorphism.

The so-called Taconic rocks had been by many of the most eminent geologists placed in the Paleozoic, a view which he held in common with Logan as late as 1868, and which was reiterated later by Dana after an extended and careful field study. Many of these rocks are highly crystalline and include gneisses. This touched a critical point in Dr Hunt's system at a later period of its growth, and he was naturally drawn into the Taconic controversy. The structural and other problems underlying this long and bitterly contested question were extremely complicated and such that the correctness of any interpretation could be ascertained only by exceedingly detailed surveys, made with such topographic maps as did not then exist. It should not be counted against Dr Hunt that from the limited reconnaissance field-work which he was able to do, he came out a partisan for any particular side. But, considering the various possible interpretations of the facts, his interpretation was naturally one in agreement with the requirements of his law of development of crystalline rocks. Thus in this controversy he held the view that the series called Lower Taconic by Emmons is of pre-Cambrian age. This series he named Taconian. In so far as western New England is concerned, it consists of the Stockbridge limestone with its underlying quartzite and overlying hydromica-schists, and has been recently shown by the stratigraphical studies of Dana, Wolff, Putnam, Dale, Hobbs and the writer, aided by the paleontological work of Wing, Walcott, Foerste, Wolff and Dale, to range probably in unbroken succession from the Olenellus Cambrian to the Hudson River group. At the top of this series he drew a great time-break, and placed above it Emmons' Upper Taconic, and assigned it to the Lower and Middle Cambrian.

A review of his recorded work shows that he was a brilliant and original thinker, and that his speculations in chemical geology were based on

a large amount of original laboratory research and on a skillful use of that of others. Such a review brings out to light also a lack of that experience in detailed field-work, both original and critical, especially in structural geology, which is essential in building hypotheses and in testing them step by step. One cannot but feel that he was seriously limited by this deficiency, and that this limitation caused him to continue through the world's half century of progress in geology to construct a history of the early globe on a plan circumscribed by conceptions formed early in his career. Throughout his time he was the leading representative of chemical geology in America, and his works contain, both on the side of original research and of speculation, very much of the material necessary to construct the same history on lines more in accord with the present requirements. On its suggestive side Dr Hunt's work in chemical geology has ranked high in both hemispheres and its influence will long continue to be felt, and in a growing science this is perhaps the rarest and most important side.

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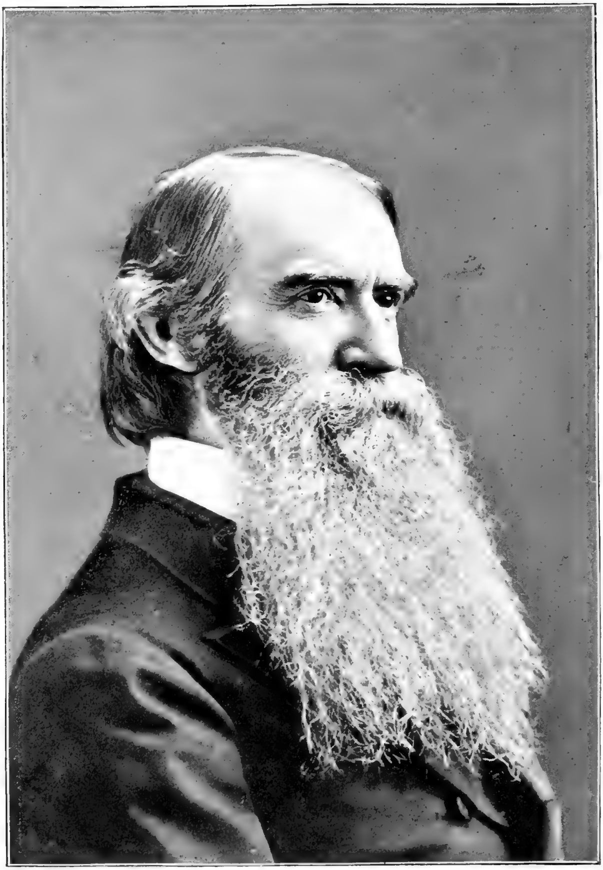

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A memorial of J. S. Newberry, in the absence of the author, was read by H. L. Fairchild.

MEMORIAL OF JOHN STRONG NEWBERRY

BY J. F. KEMP

The circle of American scientific men who, at least in the earlier periods of their work, may be most correctly described as naturalists, grows smaller year by year. The ever-widening range of facts and re-

corded observations with which an investigator of to-day must be familiar tends to concentrate attention upon more and more restricted lines. When, thus, one is removed who has left the stamp of his genius upon many departments of science, in all of which he was conspicuous, and when we sum up his many activities in such brief form as to grasp at once an appreciation of them, our admiration for his abilities is the more enhanced and our feeling of loss is the greater. Such a man was the late Professor John Strong Newberry.

Dr Newberry first saw the light in the little town of Windsor, Connecticut, December 22, 1822, and therefore at the time of his death, December 7, 1892, lacked about a fortnight of being seventy years of age. His ancestors were among the founders of Windsor, which they helped to settle in 1635. Dr Newberry's grandfather, Honorable Roger Newberry, was a director in the "Connecticut Company" that purchased the tract in northeastern Ohio known as the Western Reserve, and thither his father, Henry, removed in 1824, when the late professor was two years of age. The family settled at Cuyahoga Falls, south of Cleveland, and there Dr Newberry's boyhood was passed. The elder Newberry became actively engaged in opening up the coal resources of eastern Ohio and in obtaining an outlet for them to Lake Erie. His son was thus reared in the midst of mining and of that kind of mining which especially developed fossil plants. In his later years Dr Newberry took pleasure in recounting the delight which he felt while yet a boy in uncovering these delicately preserved fronds from their enclosing shale.

After preparation for college, the future professor entered the Western Reserve University at Hudson, Ohio, and was graduated in 1846. He next studied medicine in the Cleveland Medical School, and received his degree of M. D. in 1848. The attractions of European study led him shortly afterward to Paris, where he spent two years in further preparation in medicine. Interest in fossils prompted him also to seek instruction in paleontology, but as he was accustomed many years later to speak of the unsatisfactory character of his opportunities, they probably amounted to little. On returning to America he began, in 1851, the practice of medicine in Cleveland, and soon gained a wide clientele. It is a curious fact that in the same year in which Dr Newberry sought European advantages, Leo Lesquereux, his great contemporary, migrated to America.

While Dr Newberry's medical practice increased and many influences conspired to develop him into a settled and successful physician, his tastes for natural history kept making his profession more and more irksome. Friends at Washington were not slow in taking advantage of this and finally induced him to abandon Cleveland and active practice.

He became in May, 1855, assistant surgeon and geologist to the exploring party that was sent out by the War Department under Lieutenant R. S. Williamson to traverse the country between San Francisco and the Columbia river. Two years later his papers on the botany, zoölogy and geology of the region appeared in volume vi of the "Reports of Explorations and Surveys to ascertain the most practicable and economical Route for a Railroad from the Mississippi river to the Pacific ocean, made in 1853–'56, Washington, 1857."

Dr Newberry next became geologist to the Ives expedition, as it is generally known, from its commander, Lieutenant Joseph C. Ives. This party was sent to explore the Colorado river in 1857–'58.

After sailing up the river from the gulf of California in a little steamer to the mouth of the Grand canyon the party spent nearly a year in the study and exploration of the lower Colorado and the plateau lying eastward. Dr Newberry not only gained an acquaintance with the superb geologic sections and phenomena of erosion there afforded, but also with the Pueblo tribes of Indians, in whom he ever afterward took the deepest interest.

The geologic portion of the final report forms what is now its most valuable and interesting part. The full title is, "Report upon the Colorado River of the West, explored in 1857–'58," Washington, 1861.

In 1859 Dr Newberry was again in the field as naturalist of an expedition under Captain J. N. Macomb, which explored the San Juan country, in southwestern Colorado, and the adjacent parts of Utah, Arizona and New Mexico. Many observations on the coal seams and general geology of this country are recorded, to whose accuracy and importance later and fuller reports have given ample confirmation. The results of this expedition were not made public until 1876, owing in part at least to the demoralization of the war. They then appeared under the title, "Report of the Exploring Expedition from Santa Fé to the junction of the Grand and the Green Rivers," Washington, 1876.

Shortly after the trip was completed the civil war broke out. Dr Newberry was summoned to the newly organized Sanitary Commission, in which, on June 14, 1861, he took his place, although at the time attached to the War Department. But the work of the commission was imperative, and in September Dr Newberry resigned from the War Department and became secretary of the western branch of the commission, with headquarters at Louisville. All the operations in the Mississippi valley and its tributaries were under his direction. Distributing depots were quickly established at many points. At times Dr Newberry followed the army and was himself present at the battle of Chattanooga, overseeing the work of his organization. At the close of the war he made

his final report. It is a volume of 543 pages and exhibits the great labors performed and the enormous sums which were expended under his administration. Dr Newberry had by this time returned to Washington and had become attached to the Smithsonian Institution. He also held a professorship in the Columbian University of Washington during 1856–1857.

In 1864 the School of Mines, Columbia College, New York, was founded. and in 1866 the chair of geology and paleontology was created, and a call was extended to Dr Newberry. He accepted and remained in the uninterrupted discharge of his duties until a stroke of paralysis, December 3, 1890, made work impossible. It was never resumed.

This long interval of twenty years is marked by incessant activity, for, in addition to instruction in the college, a vast amount of investigation and writing was carried on. Opportunities for scientific work and distinction outside of New York appeared and made possible the greatest efforts of his life. When the legislature of Ohio established a state geological survey in 1869, Dr Newberry, who had all along kept his household and home in Cleveland, was called by Governor Hayes to the directorship. Active organization was soon effected and a comprehensive scheme of work was blocked out. Three reports of progress were issued, the last extremely brief. The final reports comprised four volumes on the geology of the state, two on its paleontology, one geologic atlas and a report on the zoölogy. They all appeared between 1869 and 1882. One or two were printed in German as well as in English. A large part of the field-work was done by the director himself, and the descriptions of a number of counties are from his pen. Of course the summation is also his. In paleontology notable discoveries were made of fossil fish and fossil plants. The reports on these two groups by Dr Newberry probably attracted as much attention from scientific men as any other portions of the survey's work. Observations on the geologic history of the great lakes and their relationships to the glacial period were recorded, which have proved fruitful of later results. Not a few men began their geologic work in the survey or took part in it, who have since become leaders. G. K. Gilbert, R. D. Irving, Henry Newton, N. H. Winchell and Edward Orton, the able and courteous director of the present Ohio survey, may be mentioned. Probably an error of judgment was committed in postponing the economic work until the last, for before these reports, which always have greatest value and interest to the people at large, were reached, the legislature cut short the appropriation on the ground, as one rural member said, that too much money was devoted to clams and salamanders.

Dr Newberry also did a large amount of paleontologic work for the

Illinois survey, especially on vertebrate fossils. A still more extended undertaking was the description of the later, extinct floras in the west, materials for which had been gathered by the Hayden survey. A volume of plates was issued in 1878, but, although begun nearly fifteen years ago, the manuscript is not entirely complete, and, if published, will form a posthumous work under the editorship of the professor's old student and friend, Arthur Hollick.

In association with the New Jersey survey, Dr Newberry also undertook the description of the flora of the Amboy clays. This manuscript, with some editorial completion by Mr Hollick, will also appear as a posthumous work. The description of the fossil fishes and plants of the eastern Triassic strata was pushed to a conclusion and appeared in 1888, as Monograph XIV of the United States Geological Survey. A more elaborate work on the Paleozoic Fishes of North America came out in the following year as Monograph XVI of the same survey. Both works are extensively illustrated by plates. For the preparation of these he was appointed paleontologist on the survey in 1884.

In addition to his paleontologic papers, Dr Newberry wrote also many shorter contributions for the scientific journals on subjects connected with economic geology. In this connection it may be stated that he was one of the judges at the Centennial and was the author of the report on building stone. Several papers in Appleton's Cyclopedia are from his pen, and of Johnson's Encyclopedia he was one of the editorial staff. This sketch would be incomplete without mention of the high regard that was felt for his opinion on the value of mines, both for metals and coal. His advice was often sought, and frequent trips to the west and to Mexico widened his range of observation.

When the National Academy was founded, Dr Newberry was named by Congress as one of the incorporators and became a familiar figure at its meetings. In 1867 his alma mater honored herself and him by bestowing the degree of LL.D. In the same year he was president of the American Association for the Advancement of Science and delivered the annual address at Burlington, Vermont. Likewise in 1868, soon after his coming to New York, he was chosen president of the New York Academy of Sciences, Professor C. A. Joy, the previous incumbent, gracefully and generously retiring to give the Doctor an appropriate introduction to the scientific circles of the metropolis. For twenty-four years Dr Newberry remained president of this body, and during the last years of his life and at the time of his death was its honorary president. Dr Newberry was also president of the Torrey Botanical Club and occupied the position during the ten years between 1880 and 1890.

Largely in immediate recognition of his paleontologic works, the Geo-

logical Society of London conferred on Dr Newberry in 1888 the Murchison gold medal, which is awarded by the society for distinguished services in geology. In presenting the medal President Judd, and in receiving it in behalf of Dr Newberry, Sir Archibald Geikie referred in a most appreciative way to his work. When the long-pending Geological Society of America finally took form at Cleveland in 1888, Dr Newberry was present and shared in the preliminaries of organization. At the second election of officers, in New York, December 26, 1889, he was chosen first vice-president. The crowning honor of his life came, however, in 1891.

In the late seventies the subject of an International Congress of Geologists was broached in the American Association and Dr Newberry was appointed one of the committee to carry the matter through. The movement led to the organization of the congress, which has now had four meetings at intervals of three years and in several countries. The last one was in Washington in August, 1891, and chose for its presiding officer the one in whose memory these lines are penned. The honor was a fitting tribute to a long and fruitful life, but it came after its recipient was too weakened to take the chair. From his far-distant summering place on Lake Superior he was forced to send his messages of greeting to the congress.

It was in the winter of 1889–'90 that exhausting labors began to tell heavily on a constitution that had seemed so proof against fatigue that it knew not how to yield. A heavy cold and attendant weakness gave warning that certain limits must be regarded, but the professor, after a brief absence, again appeared before his classes. When the long summer vacation of 1890 came, he wrought day after day with an amanuensis on his report upon the Amboy flora. The strain was too severe and culminated the following December with a paralytic stroke, from the effects of which the honored teacher and investigator never recovered.

Dr Newberry's skillful touch has been felt in almost all lines of geologic work and in almost all departments of natural history. He was a most indefatigable collector, and the museum which he leaves at Columbia is a monument to his memory. Its wealth in fossil fish makes it unique and famous among geologic museums.

Dr Newberry had also a strong passion for music, and in his earlier career was wont to solace the long hours of western expeditions with his violin. He was likewise gifted with skill in sketching, such that many illustrations of fossils and of scenery in his reports are from his own hand. He wrote in charming and attractive literary style, and in descriptions of the grand phenomena of the west often manifested a highly artistic use of language.

In his scientific work he sometimes displayed almost the insight of a seer, and from his ability to grasp, as it were by intuition, the bearings of many widely isolated facts, he has shown a quite prophetic instinct. His determinations of strata in the west, although based on the hasty itineraries of exploring parties, have been very generally corroborated by later and more deliberate work. The same is true of his early views on the origin of petroleum, and on the buried channels that have been since discovered around nearly all the waterfalls of the central part of the country. He was withal extremely conservative on many doubtful points and before his classes was always very cautious of statement. With his students his relations were marked by great kindliness, and by them he was universally beloved.

Dr Newberry was married in Cleveland, in 1848, to Miss Sarah B. Gaylord, who, with six of their seven children, survives him.

The following bibliography contains those titles of Dr Newberry's writings which are to be regarded as broadly included under geologic science. A chronologic list of all his writings is published in the Transactions of the New York Academy of Sciences, volume xii, pages 174–185, and in the "American Geologist" for July, 1893. A list of his botanic papers, with a list of the plants named after him, is printed in the Bulletin of the Torrey Botanical Club for March, 1893.

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Dr Newberry was also one of the editors of Johnson's Encyclopædia, having charge of geology and paleontology. He wrote many articles on these subjects for its pages in 1875 and the years immediately following.

Biographic sketches of Dr Newberry have been published in all the current biographic dictionaries and cyclopedias. Portraits of him appear accompanying such sketches in Men of Progress, 1870–'71, page 317, and Contemporary Biography of New York, volume v, 1887, page 255. The Popular Science Monthly, volume ix, page 491, 1876, contains a sketch, with portrait, and in Fairchild's History of the New York Academy of Sciences there is an excellent artotype.*

A memorial of J. H. Chapin, in the absence of the author, was read by C. H. Hitchcock.

MEMORIAL OF JAMES HENRY CHAPIN

BY W. M. DAVIS

James Henry Chapin, an original member of our Society, was born in Leavenworth, Indiana, on December 31, 1832. He died in South Norwalk, Connecticut, on March 14, 1892, in his sixtieth year. He was a

*Since his death memorials have appeared, with portraits, in the Engineering and Mining Journal, December 17, 1892, page 581; the Scientific American, December 31, 1892, page 423; the School of Mines Quarterly, January, 1893, page 93, with two steel portraits, one taken in 1865 and one in 1887; the Bulletin of the Torrey Botanical Club, March, 1893, with an artotype; and in the Transactions of the New York Academy of Sciences, volume xii, March, 1893, a memoir, by Professor H. L. Fairchild, republished by the Scientific Alliance of New York, March, 1893. A memorial, by Professor J. J. Stevenson, appears in the American Geologist for July, 1893, with a revised chronologic bibliography, by J. F. Kemp.

descendant in the eighth generation of Samuel Chapin, who came from Wales to Dorchester, Massachusetts, in 1636 or 1637, moving to the outlying settlement of Springfield, Massachusetts, in 1842. His father was Gustavus W. Chapin, of Cooperstown, New York; his mother, Mary McNaughton, of Ohio. One of the family of nine children of a hard-working farmer, Dr Chapin showed a characteristic American spirit, being a self-supporting student in his youth and an active worker in varied directions during his maturity. He was graduated at Lombard college, Galesburg, Illinois, in 1857, and spent a time there in teaching mathematics and natural science; but he soon turned toward the ministry and occupied Universalist pulpits in Illinois for several years. In 1857 he married Helen M. Weaver, who died in 1871, leaving a daughter. During the later years of the rebellion he was actively and successfully engaged in California in raising funds for the Sanitary Commission.

It is not until 1871 that Dr Chapin's attention was especially directed toward geology. It had been previously a subject of general interest to him, but on accepting the chair of geology and mineralogy in the St. Lawrence University in northern New York his thoughts were more turned toward our science. Between 1873 and 1885 he also held the pastorate of the Universalist church at Meriden, Connecticut, where he resided the greater part of the time, his duties at the St. Lawrence University requiring but the smaller part of the year. In 1875 he was called to the presidency of his *alma mater* at Galesberg, Illinois, but felt unable to accept the position.

At Meriden, in 1878, he married Kate A. Lewis, daughter of Honorable Isaac C. Lewis, prominently connected with the business development of that busy city. His travels abroad and his lectures at home during the past twenty years led to the publication of several volumes of general interest. In 1889 he was elected to the Connecticut legislature, where he was active in introducing a bill for a state topographic survey similar to the surveys previously established in Massachusetts and Rhode Island. He was appointed one of the three commissioners to superintend the prosecution of the survey, and through his interest in the work he made it widely known to the people of the state. The schools of Meriden had his close attention, and the high school was his particular care. He was closely identified with the Meriden Scientific Association, an active local institution, of which he has been president. He frequently took part in its meetings and excursions, his interest being aroused in particular by the ancient volcanic phenomena of the district. His death was deeply felt by the community in which he was so actively engaged.

The following is a list of the geologic writings of Dr Chapin:

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The hanging Hills; The Trap Ridges of Meriden; Notes of Africa: *Trans. Meriden Sci. Assoc.*

The topographical Survey of Connecticut: *Trans. Meriden Sci. Assoc.*, January, 1890, p. 7.

Cycadinocarpus chapini: *Trans. Meriden Sci. Assoc.*, January, 1891, p. 1.

Some geological Features of Meriden: *Trans. Meriden Sci. Assoc.*, January, 1891, p. 4.

Magazine articles on Science and Religion and Genises and Geology.

A Year's Progress in Science: *Meriden Daily Republican*, February 9, 1892.

The President, following the reading of the memorials, declared the morning session adjourned.

The Society reassembled at 2 o'clock p. m., and the reading of papers was declared in order.

The first paper upon the printed program was—

ON THE COALS AND PETROLEUMS OF THE CROW'S NEST PASS, ROCKY MOUNTAINS

BY A. R. C. SELWYN

Remarks were made by the President and I. C. White.

The second paper was—

ON THE GEOLOGY OF NATURAL GAS AND PETROLEUM IN SOUTHWESTERN ONTARIO

BY H. P. H. BRUMELL

Remarks were made in discussion by Dr I. C. White, who said:

That Mr Brumell's paper was confirmatory of Professor Edward Orton's conclusion that the limestone, when a repository of oil or gas, is dolomitic and porous, and that the probable reason why the Dundas anticlinal contains no gas is because the Trenton limestone there is not dolomitic.

Mr H. M. Ami said:

That the Trenton is throughout not dolomitic; that the dolomitic layers below are of the Calciferous.

Another paper by the same author:

NOTES ON THE OCCURRENCE OF PETROLEUM IN GASPÉ, QUEBEC

BY H. P. H. BRUMELL

These two papers are printed as pages 225–244 of this volume.

On account of the absence of the author the following paper was presented by title:

SOME FEATURES OF THE PHOSPHATE-BEARING ROCKS OF OTTAWA COUNTY, PROVINCE OF QUEBEC

BY ELFRIC DREW INGALL

In the absence of the author the next paper was read by F. D. Adams:

NOTE ON FOSSIL SPONGES FROM THE QUEBEC GROUP (LOWER CAMBRO-SILURIAN) AT LITTLE METIS, CANADA

BY J. WILLIAM DAWSON

[*Abstract*]

The object of this note was to introduce to the Society some specimens and a photograph in illustration of a very remarkable and interesting discovery of Lower Paleozoic sponges, made accidentally in 1887 by Dr B. G. Harrington, F. G. S., and followed up by the writer.

In two or three thin bands, in black shales belonging to a markedly unfruitful portion of the Quebec group, there occur a number of fossil sponges perfectly flattened and with their originally silicious skeletons replaced with pyrite. They thus form very delicate tracery on the surfaces of the shale. By careful quarrying in these beds there were discovered up to 1889 thirteen species, which were described and figured by the author and Dr Hinde, of London, in the Transactions of the Royal Society of Canada for that year. Six of these belong to the primitive genus *Protospongia* of Salter, and of most of these we have the entire forms, showing their oscula, protecting spicules and anchoring rods, details which were previously unknown. One species belongs to the genus *Cyathospongia* of Walcott, previously known in the Utica shale. Another, cylindrical and curiously hispid, has been placed by Hinde in a new genus *Acanthodictya*. Another appears to belong to genus *Hyalostelia* of the same author. Three others, which seem to have simple and not hexactinellid spicules, have been placed in the genera *Sasiothrix* and *Halichondrites*. The thirteenth has not yet been named, being imperfectly preserved.

Since 1889 the excavations have been continued, but until the present year with the result only of finding additional specimens of the species already known. Last summer, however, the author was so fortunate as to discover a very large and remarkable form, of which a photograph was exhibited, the original slab, now in

the Peter Redpath Museum of McGill University, being too fragile to admit of carriage. This new species must have been of sack-like form and as much as fourteen inches in diameter. Its walls consist of rhombic meshes about half an inch wide. These meshes are made up of delicate spicules loosely twisted together and apparently branching at the angles of the meshes. They seem to have been filled in and covered with small cruciform or simple flesh spicules which toward the sides conceal the meshes of the framework. The hair of the specimen and its anchoring rods are wanting, but on the same surface are numerous fragments of anchoring rods which would seem to have belonged to this species. They are composed of many long, slender spicules similar to those of the body, but closely twisted so as to form a rope or cord, on which are placed minute tubercles or flat projections, so as to give greater holding power. This remarkable sponge is probably the largest and most complex yet found in formations of so great age. Dr Hinde, the author of the British Museum catalogue of fossil sponges, has kindly undertaken its detailed description, and proposes to place it in a new genus, *Palaeosaccus*.

It was further remarked that the discovery of so many species on what represents a single sea bottom illustrates in a remarkable manner the abundance of sponges at this early date, and shows how much may be learned by following up productive beds in the older formations, in which it often happens that great thicknesses of rock are unproductive of fossils.

The only other fossils associated with these sponges are a species of *Linnarssonia*, *L.* (*Obolella*) *pretiosa* of Billings, and a slender, branching fucoid (*Buthotrephis pergracilis*). In neighboring sandstone beds there are fragments of *Retiolites ensiformis* of Hall, and the curious radiating markings known as *Astropolithon*, along with impressions of worm-burrows.

Remarks were made by H. M. Ami.

The following two papers were read by the author:

NOTES ON CAMBRIAN FOSSILS FROM THE SELKIRKS AND ROCKY MOUNTAIN REGION OF CANADA

BY HENRY M. AMI

ON THE POTSDAM AND CALCIFEROUS TERRANES OF THE OTTAWA PALEOZOIC BASIN

BY HENRY M. AMI

Remarks upon the subjects of these papers were made by C. H. Hitchcock, A. R. C. Selwyn and C. R. Van Hise.

The next communication was entitled:

NOTES ON THE DEVONIAN FORMATION OF MANITOBA AND THE NORTHWEST TERRITORIES

BY J. F. WHITEAVES

The following paper was then read:

DISTINCT GLACIAL EPOCHS AND THE CRITERIA FOR THEIR RECOGNITION

BY R. D. SALISBURY

During the animated discussion which followed the reading of this paper remarks were made by W J McGee, C. H. Hitchcock, Warren Upham, Robert Bell, B. K. Emerson and the President. The paper is published in full in The Journal of Geology, volume i, pages 61–84.

The last paper of the afternoon session was—

PLEISTOCENE PHENOMENA IN THE REGION SOUTHEAST AND EAST OF LAKE ATHABASKA, CANADA

BY J. B. TYRRELL

Remarks were made by C. H. Hitchcock, Warren Upham and Robert Bell.

Announcement of the lecture in the evening was given, and the Society adjourned.

EVENING SESSION OF WEDNESDAY, DECEMBER 28

The Society was called to order at 8 o'clock in the Normal School auditorium. A lecture was given upon the following subject:

A FOSSIL EARTHQUAKE

BY W J MCGEE

[*Abstract*]

With a single exception, the traveler by steam-packet on the lower Mississippi finds the river flanked by alluvial banks so low that during great freshets they are overflowed all the way from Cairo to the Gulf, save where protected by natural or artificial levees. The exceptional locality comprises nearly all of Lake county, Tennessee, and a considerable area in Missouri, on the opposite side of the river. This area, which is some 20 miles in mean diameter, bulges upward in the form of a low dome, 20 or 25 feet above the general level of the alluvial plain. East of it lies Reelfoot lake; west of it the "Sunk country" of southeastern Missouri and northeastern Arkansas, and through its crest the Mississippi has cut a meandering trough. When the surface of the dome is examined it is found to be scored by broad trenches like the channels of waterways; moreover, these trenches are flanked by natural levees so characteristic of the Mississippi flood-plains that they are at once recognized as bayous from which the waters have been removed. The structure of the dome is revealed in the channel of the Mississippi. It is composed of a sheet of alluvium, 10 to 30 feet thick, identical in character with the modern

river deposit flooring the entire flood plain, and unconformably below lies the dense, tenacious blue or greenish Port Hudson clays, which underlie the flood plain throughout. Thus the structure is similar to that of other parts of the "Delta," save that the deposits lie 20 or 25 feet higher.

The configuration and composition of the dome indicate that it was originally a part of the broad flood plain extending from the mouth of the Ohio to the Gulf, and its exceptional altitude and general conformation suggest a localized uplift. Moreover, several of the dry bayous enter Reelfoot lake squarely or obliquely, and when this occurs there is no trace of delta-building, and both channel and natural levees may be traced for long distances in the lake; indeed, for some distances they may be traced throughout their extent and found to connect in the form of a fairly definite drainage system. This absence of deltas indicates that the uplift or deformation occurred suddenly. Furthermore, it is found that while great cypresses, sycamores and poplars, sometimes two or three centuries old, grow over the general surface of the dome, no trees older than seventy or seventy-five years grow within the unoccupied bayous; from which it may be inferred that the uplift occurred at least seventy or seventy-five years ago, and probably not much earlier.

Reelfoot lake is a shallow water-body of irregular form, perhaps five miles in average width and twenty miles in length from north to south, lying between the Lake county dome and the base of the upland scarp, a dozen to a score of miles east of the river. Its depth increases very gradually from its western margin nearly to the eastern shore, where at low water its depth is twenty or thirty feet. At high water on the Mississippi its depth is some twenty feet more, since it then becomes part of the general flood by which the Lake county uplift is transformed into a double island. The lake is not an uninterrupted sheet. Here and there, particularly toward the western side, groves of sickly cypresses spring from its bottom and half shadow the water surface with puny branches and scant foliage, and here and there throughout all portions of the water body, save in the channels of the old bayous, gaunt cypress trunks with decaying branches stand, sometimes a dozen to the acre, numbering many thousands in all. Moreover, between the decaying boles, rising a score to a hundred feet above the water, there are ten times as many stumps, commonly of lesser trees, rising barely to low-water level. Now, while the subsurface structure beneath Reelfoot lake is not revealed, the phenomena of the lake grade into the phenomena of the dome. The lake bottom is meandered by waterways whose combined channels and natural levees prove them to be bayous similar to those of the Mississippl flood-plain; along and between the bayous cypress stumps and boles are scattered just as they are distributed over much of the modern flood-plain, and dry bayous and drowned swamps alike indicate that the land beneath Reelfoot lake was depressed. Moreover the transformation of the area from land to lake without filling the old bayous by sediment indicates that the depression occurred suddenly. Furthermore the presence of the cypress stumps and trunks, particularly in the deep portions of the lake where the drowning must have been complete, indicates that the date of the subsidence was not remote.

The upland scarp overlooking the Mississippi flood plain on the east, from Baton Rouge to the mouth of the Ohio, is everywhere mantled by loess or a loam of closely related character, and the mantle, as well as the underlying rocks, is deeply scored by erosion. Accordingly the upland margin is made up of steep salients and cusps and narrow divides separating a myriad ravines. Now, on approaching the Reelfoot country from the north or the south, certain minor topographic features

appear and finally culminate in that part of the scarp overlooking the lake. The narrowest divides are longitudinally cleft by trenches yards in width and often several feet in depth; the steeper outlying cusps are divided by similar trenches, and frequently the salients are cleft by such trenches cutting across their steeper slopes or radiating in three or four lines from the apex. Furthermore, along the face of the scarp opposite the lake, ancient landslips, with their characteristic deformation of the surface, are found in numbers, and over the landslips and along the sides of the trenches on the summit trees are frequently thrown out of the perpendicular. These features suggest a sudden and violent movement by which the highly unstable topographic forms of the upland scarp were in part broken down and thrown into more stable positions. On examining the inclined trees it is usually found that the great boles two or more centuries old are inclined from root to top, though the younger trees of seventy or seventy-five years usually stand upright, and that the trunks of a century to a century and a half in age are commonly inclined near the ground, but are vertical above. Thus the forest trees flanking the fissures and clothing the scarp give a trustworthy and fairly accurate date for the production of the minor topographic features—a date determined by much counting of annual rings to lie between seventy-five and eighty-five or ninety years ago.

While in general the flood-plain of the Mississippi is essentially alike in composition from Baton Rouge to Cairo, a minor distinction is found over the Lake county dome and in its vicinity: The flat-lying alluvium is sometimes interrupted by irregular ridges of gravel and coarse sand, sometimes by double ridges with irregular trenches between; and now and then elongated mounds of similar gravel and coarse sand occur, either isolated or in lines. When in cultivated lands, the ridges and mounds are reduced but give character to the soil throughout entire fields; but when in woodland, they affect the forest to the extent that the larger trees along their flanks are frequently thrown out of the perpendicular as are the trunks of the upland, while only young trees about seventy-five years old and less grow in the trenches.

Now it is conceivable that areas may be lifted like the Lake county dome or depressed like Reelfoot lake by gentle diastrophic action; it is conceivable even that a group of contemporaneous landslips and fissures in a hilly scarp might be developed by a variety of causes or movements coinciding fortuitously; but the gravel ridges and mounds of the flood-plain are homologous with the craterlets, sand spouts and fissures produced by earthquakes, and they are unlike phenomena produced by any other known cause. Moreover the landslips and trenches of the scarp are more perfectly and simply explained as the product of an earthquake than in any other way. Again, the depression of the land beneath Reelfoot lake is analogous to surface movements known to be produced by earthquakes; and it might be shown through the application of the principle of isostasy that the uplift in the center of the Mississippi lowland with the depression on both flanks toward the more heavily loaded uplands, is more readily explicable as an earthquake product than in any other way. Accordingly the assemblage of phenomena may be explained on the hypothesis of an earthquake of great severity, and cannot well be explained on any other hypothesis. Thus the peculiar features of Lake county, Tennessee, and contiguous territory, may justly be regarded as a physical record of a great earthquake, the date of which is fixed by attendant phenomena at from seventy-five to eighty-five years ago.

Assuming the verity of the hypothesis, one out of its many consequences may be considered. The Lake county dome lies athwart the course of the Mississippi, which is here well out in the flood-plain; so that, if the lifting was effected suddenly, the flow of the river must have been obstructed. Now the declivity of the lower Mississippi is so slight and the land so low that the back water due to any obstruction spreads over an enormous area and reaches a vast volume; moreover, under the hypothesis, the Reelfoot lake depression was formed contemporaneously and the lake must have been filled by the water of the river taken not simply above the obstruction but (by reason of geographic relations which need not be set forth in detail) from many miles above, *i. e.*, at what is now the site of Hickman. Accordingly it may be considered certain that an immediate effect of the earthquake must have been a reversal of the flow of the Mississippi about what is now the the northern extremity of Lake county, at least for many hours.

There are voluminous, though somewhat vague and little known, records of a great earthquake centering about the Spanish settlement of New Madrid, in southern Missouri, beginning near the end of 1811 and continuing with gradually diminishing intensity through the succeeding year and most of 1813. These historical records embrace a classical memoir by Dr S. L. Mitchill; an account by a kinsman of the eminent professor of geology in Harvard college; a detailed paper in the American Journal of Science, by Louis Bringier, a reputable engineer of New Orleans; detailed descriptions in the ephemeral press and in the books of the day; an elaborate description by the geographer Flint; a careful and extended statement by Sir Charles Lyell; and an unpublished circumstantial account by a grandfather of the writer, who resided in western Kentucky throughout the entire earthquake period. From these various accounts, especially that of Mitchill, it can be shown, in so far as historical records are trustworthy, that the New Madrid earthquake was one of great severity and was unparalleled in extent; it was felt from New Orleans on the south to Fort Dearborn (Chicago) and Detroit on the north, and from Washington and Charleston on the east as far westward as explorers had then penetrated, thus affecting fully one-third of the area of the United States or not less than a million square miles.

For various reasons the historical records of the New Madrid earthquake have been looked upon with distrust, and a communication has been laid before one of the leading scientific societies of the country by an eminent savant for the purpose of proving that no such earthquake ever occurred. One of the reasons for the distrust of the records was the allegation by Shaler, by Bringier, and by nearly all contemporary witnesses that the flow of the Mississippi river was changed, and that it ran upstream for hours; another reason for distrust was found in the oft-repeated allegations that during the tremor the earth opened and fountains of water flowed from the fissures, bringing up great quantities of sand and gravel (as well as "coal" and the type specimen of the now well-known *Oribos cavifrons*), from unknown depths; but the latter allegations are in perfect accord with recent observations on earthquakes, notably, those of Charleston and Kach and Cachar, while the reversal of the flow of the Mississippi is unmistakably recorded in the present physical features of the region, for the summit of the Lake county dome is less than a score of miles from the still existing town of New Madrid.

The lecture was illustrated by lantern views. In moving and seconding a vote of thanks to the lecturer addresses were made by Sir James

Grant and Sheriff Sweetland. Following the adjournment an informal reception was given the Society.

Session of Thursday, December 29

The Society was called to order by President Gilbert at 10.30 o'clock a m.

Mr J. S. Diller read the report of the Committee on Photographs, which was accepted by consent. It was voted to continue the committee (J. F. Kemp, W. M. Davis, J. S. Diller) and to appropriate fifteen dollars ($15.00) for the use of the committee during the next year. The report is as follows:

THIRD ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During the year 105 photographs have been presented to the Society, and the collection now numbers 740. In the register the donors' numbers are given in parentheses for the convenience of those who may wish to purchase photographs.

The collection remains with the secretary of the committee, Mr J. S. Diller, at the United States Geological Survey, Washington, D. C., where it is open to the examination of members of the Society. During the year it has been examined by a number of members and many photographs have been ordered for educational institutions.

The collection was exhibited at both the Rochester and Ottawa meetings. On this account the expenses of the committee were a little more ($11.67) than last year, but as the amount appropriated for the use of the Committee was $15.17, there remained at the close of the annual meeting a balance of $3.50.

The committee solicits contributions, such as are indicated in previous reports. Contributions may be sent to Professor J. F. Kemp, Columbia College, New York city; Professor W. M. Davis, Harvard College, Cambridge, Mass., or to Mr J. S. Diller, U. S. Geological Survey, Washington, D. C.

Register of Photographs received in 1892

Photographed and Donated by W. H. Jackson, Denver, Colorado

Numbers 640 to 650, inclusive, size, 21 x 16 inches; price, mounted, $2.50; unmounted, $2.00. Discount of 25 per cent on orders of $50.00 or over. Lantern slides from all negatives, 50 cents each. Four slides from same negative, 30 cents each.

636 (1632). Grand canyon of the Colorado. Size, 21 x 74 inches; mounted, $17.50; not mounted, $15.00.

637 (1008). Pike's peak from the Garden of the Gods. Size, 20 x 43 inches; mounted, $12.00; not mounted, $10.00.

638 (1098*p*). Yellowstone canyon and falls. Size, 19 x 44 inches; mounted, $12.00; not mounted, $10.00.

639 (1661p). Mammoth hot springs; Cleopatra and Jupiter terraces. Size, 17 x 38 inches; mounted, $7.50; not mounted, $6.00.

640 (1095). Yellowstone canyon.

641 (1657). Pulpit terraces; Mammoth hot springs.

642 (1105). Old Faithful; a geyser in action,

643 (1106). The "Castle" geyser and Crested spring; Yellowstone National park.

644 (1656). Index peak; Wyoming.

645 (1669). Fremont's peak and lake; Wind River mountains, Wyoming.

646 (1667). Teton range; from the east.

647 (1666). Teton range; from Jackson's lake.

648 (1653). Cloud peak; Big Horn mountains, Wyoming.

649 (1651). Matteo teepee, or Devil's tower.

650 (1344). South dome; from Glacier point.

Photographed and Presented by Professor H. F. Reid, Case School of Applied Science, Cleveland, Ohio

Size, $5\frac{1}{2}$ x 8 inches. Copies of these photographs furnished to members of the Geological Society only at the following rates: Unmounted, 20 cents; mounted, 25 cents; by Frank R. Stoll, 106 Euclid avenue, Cleveland, Ohio. Orders must include Mr Reid's numbers, which are given below in parentheses.

651 (258). Glacier draining into Tidal inlet.

652 (259). Mountain near Tidal inlet.

653 (300). Muir glacier from altitude of 2,000 feet; looking eastward.

654 (303). Mount Case.

655 (305). Mount Young.

656 (310). Large iceberg discharged from Muir glacier; about 100 feet out of water.

657 (312). Muir glacier; from Caroline shoals.

658 (314). Muir glacier; from Sebree island.

659 (318). Mountains at the head of Geikie inlet.

660 (330). Mount Wright; from Sebree island.

661 (333). Rounded limestone on Drake island.

662 (347). View over Hugh Miller inlet.

653 (348). View over Hugh Miller inlet.

664 (354). Geikie glacier; Hugh Miller inlet.

665 (362). Mountains between Tidal and Queen inlets; from across the bay, looking northeast.

666 (364). View in Hugh Miller inlet.

667 (374). First northern tributary of Muir glacier; from *V*.

668 (379). Western tributary of Muir glacier; from *V*.

669 (380). Mount Wright; from *V*.

670 (381). Muir glacier; from *V*.

671 (385). Junction of Girdled with Muir glacier.

672 (386). Junction of Girdled with Muir glacier.

673 (387). Looking down Endicott valley.

674 (389). Junction of Girdled with Muir glacier.

675 (395). Near head of Rendu inlet.

676 (398). Mount Fairweather; upper part of Glacier bay.

677 (400). Upper part of Glacier bay.
678 (407). Looking up Rendu inlet; from Halfbreed island.
679 (409). Carroll glacier.
680 (410). Carroll glacier.
681 (413). Glacial scratches at the north end of Sebree island.
682 (414). Muir glacier and Mount Case; looking eastward.
683 (418). Stream terraces at end of Muir glacier.
684 (420). Ice front of Muir glacier.
685 (434). Top of Mount Verstova; near Sitka.

Photographed and Presented by Professor C. W. Hall, Minneapolis, Minn.

Size, 4½ x 7¾ inches.

686 (1). Quarry in gneiss; Morton, Minn.
687 (2). Glaciated surface of gneissic rocks; Morton, Minn.
688 (3). Exposure of quartzite conglomerate; near New Ulm, Minn.
689 (4). The Dalles of the Saint Croix; Taylor's Falls, Minn.
690 (5). Columnar structure of diabase; Grand Marais, Minn.
691 (6). "Basal conglomerate;" Taylor's Falls, Minn.
692 (7). The Potsdam sandstone; Osceola Mills, Wis.
693 (8). Fault in the Magnesian series; near Hastings, Minn.
694 (9). Contact of Trenton limestone and Saint Peter limestone; Minneapolis, Minn.
695 (10). Displaced Trenton limestone; Saint Paul, Minn.

Photographed and Presented by Mr J. Stanley-Brown, Washington, D. C.

Views on the Seal islands, Bering sea. Size, 7¼ x 9½ inches

696. Miak; near Bogoslôv, Saint Paul island.
697. Miak; near Bogoslov, Saint Paul island.

Photographed and Presented by Mr H. G. Bryant, Philadelphia, Pa

Kodak views of the Grand river and falls of Labrador. Size, 4½ x 3¾ inches

698. Rapids above the falls.
699. Brink of the falls.
700. The Grand falls of Labrador.
701. Looking up stream above the falls.
702. Canyon below the falls.
703 (1). Cockle's Head; near St. John's, Newfoundland.
704 (2). Outlet of Grand lake, Labrador.
705 (3). Mountaineer Indian lodge on Grand lake.
706 (4). View looking down Grand river from lower falls.
707 (5). Part of lower falls of Grand river.

708 (6). "Dinner time."
709 (7). Rocky headland; Lake Wanakobou.
710 (8). Portaging around the Ninipi rapids.
711 (9). Camp at the head of navigation.
712 (10). View on Lake Wa-na-ko-bou.
713 (11). Cascade near Grand river above Mouni rapids.
714 (12). View on interior plateau of Labrador, showing glacial bowlders.
715 (13). Typical bowlder of the interior plateau.

Presented by U. S. Geological Survey

Photographed by W. P. Jenney

716. The anticlinal at the termination of the Ozark uplift in the northeastern corner of Indian Territory on Spring river about six miles south of Baxter, Kansas; panoramic view of four 6 x 8 inch photographs.

Photographed and presented by Ben Haines, New Albany, Ind

Size 8 x 10 inches; price, 50 cents each

24 views of Mammoth cave and vicinity

717 (04). First saltpeter vats.
718 (05). Old saltpeter pipes.
719 (08). Standing rocks.
720 (013). Stone cottage.
721 (014). Giant's coffin.
722 (017). Bottomless pit.
723 (022). The post-oak pillar.
724 (029). The arm-chair.
725 (030). The elephants' heads.
726 (036). The Egyptian temple.
727 (037). Bacon chamber.
728 (055). Stalactites in Croghan's hall.
729 (056). End of the cave.
730 (057). Star chamber.
731 (060). An alcove in Gothic avenue.
732 (065). Head of Echo river.
733 (0101). White's cave; Humbolt's pillar.
734 (0106). White's cave; the royal canopy.
735 (0124). Mammoth Cave hotel.
736 (218). Wyandotte cave; the throne.
737 (220). Wyandotte cave; Monument mountain and Wallace's grand dome.
738 (235). Wyandotte cave; Niagara falls (No. 1).
739 (524). Marengo cave; "Cupid's net."
740 (529). Marengo cave; Washington's plume.

The scientific program was declared in order, and the first paper was:

NOTES ON THE GLACIAL GEOLOGY OF WESTERN LABRADOR AND NORTHERN QUEBEC*

BY A. P. LOW

Contents.

Glacial Phenomena of the Region.—As may be supposed, there is no marked difference between the glacial phenomena of the interior of Labrador and those of more southern Canada—they all point to a great mass of ice in motion. As the central divide of the interior has not yet been visited the conditions of the surface there are unknown, but it will probably be found to differ but little from the portions already explored. The watershed between the rivers flowing into the gulf of Saint Lawrence and those of Hudson bay acted as a dividing line to the direction of the later ice movement. This height of land is a marked feature in the region for over fifty miles to the north and south of Lake Mistassini, where it runs roughly north-northeast and south-southwest, or parallel to the longer axis of that lake. The country to the southeast of the divide is from 200 feet to 400 feet higher than that to the north, the descent from the one to the other being quite sharp. Near the summit of the slope toward the Saint Lawrence the finer material of the till is abundant and the surface rock is not deeply grooved or striated. As the slope is descended the striæ are more deeply marked and their course is very persistent, being nearly due north and south to beyond Lake Saint John, where the highlands of the Saint Lawrence border appear to have formed an obstruction to the bottom of the moving ice and caused it to change its course locally, so as to pour out into the Saint Lawrence valley through any convenient pass between the hills.

North of the divide all rock exposures are deeply scratched and grooved, the direction of the striation being from N. 30° E. to S. 30° W., or parallel to the steep escarpment of the watershed. Here the glacial action appears to have been much more intense than on the southern slope; all the finer material being removed, leaving only an innumerable number of bowlders to partly cover the deeply grooved rock. The only place where quantities of the finer drift material remain is along the foot and sides of the escarpment, and this may be the remains of a lateral moraine, but cannot be stated to be such, as no detailed examination of it has been made.

The great lakes Mistassini and Mistassinis and the other large lakes strung out in line with them to the southwest lie parallel to the direction of the striæ and owe their origin to the action of the ice, which has scooped their deep basins out of the comparatively soft, flat-bedded limestones of Mistassini and the altered hornblende and chlorite slates of the lakes to the southwest, leaving the granites, gneisses and diorites to form the higher lands surrounding them.

Northward from Mistassini toward the East Main river the striæ have every-

*Published by permission of the Director of the Geological Survey of Canada.

where a N. 30° E. direction, but when that river is reached these are found to be partly obliterated by a newer set coming from N. 50° E. This direction of the newer set changes slowly to N. 60° E. as the river is descended, the older set being seen from time to time on favorably protected rock surfaces. A remarkable feature of the country to the northward of Lake Mistassini is the number of low hills made up wholly of rounded bowlders. These lie parallel to the direction of the striæ and culminate in sharp, narrow ridges that slope at high angles on either side. These bowlder ridges are at times connected with rocky hills, but more often stand up independently.

On the Big, Great Whale and Clearwater rivers a similar condition of glaciation is found, the direction of the striæ following the general slope of the country. Along the Big river it is from N. 70° E.; on the Great Whale from S. 70° E., and along the Clearwater from nearly due east.

On the coast of Hudson bay the striæ do not run in any one direction, but conform with local slopes. Here as many as four sets of striæ have been observed on the rocks; any or all of these may mark the direction of local glaciers found toward the close of the period on the rocky highlands facing the bay.

The composition of the drift is largely local, but bowlders from known localities are at times found transported from fifty to one hundred miles from their original sources. The limestones of Mistassini are found over sixty miles to the south-southwest of the nearest known bed. Bowlders of this limestone, along with others of Huronian rocks, are not uncommon in the drift of the southern slope to within a few miles of Lake Saint John. As no areas of these rocks are known to exist in the region south of the watershed, at some time, probably during the period of greatest accumulation, the ice-cap must have moved up over the height of land, carrying with it fragments of the rocks on the north side and scattered them over the southern slope, where they are now found, over one hundred miles from their known source.

On a hill some 300 feet above Clearwater lake a bowlder of Silurian limestone was found. This tends to prove the previously supposed presence of a basin of rocks of this age in the level country south of Ungava bay, as the striæ show that the bowlder must have come from that direction. A chain of islands extends up the eastern third of James bay. These are undoubtedly of glacial origin and are the remains of a terminal moraine. Although they have been submerged at or subsequent to their formation they still preserve all the characteristics of such an origin, and the action during submergence has only slightly altered their external structure. They rise in their highest parts from 150 to 200 feet above the present sea-level and are wholly composed of unstratified till. Their surface is uneven, being dotted with small rounded lakes and ponds, while the hummocks of bowlders have been flattened out and settled into compact masses by the later wave action. Their faces are cut into terraces, but there are no stratified deposits anywhere. This moraine marked the limit of the glacier at a halt during the period of retrocession and was not the limit during the time of greatest glaciation. Then the ice pushed down from the interior of Labrador, crossed Hudson bay, and passed up over the low country on the western and southwestern side, and probably crossed the watershed and descended into Lake Superior. Of this we have evidence, in the direction of the striæ and the presence of Silurian and Devonian limestone bowlders in the drifts, to show that this was the direction of the ice-flow, along the rivers falling into the southern and southwestern portions

of James bay, the limestone being transported from the lower flat region about the bay far inland over the higher interior Archean country.

The retrocession of the glacier from the island moraine to the mainland is marked by the morainic matter that fills the bay inside the boundary of the outer islands.

Pleistocene Changes of Level in Labrador.—At the close of the glacial period there was a marked elevation of the western part of Labrador. The extent and limits of this elevation can be traced by the deposits of stratified sands and clays that now cover the lower margin of the peninsula. On the Rupert and East Main rivers these deposits are found a long distance inland. On the latter river continuous deposits are met with for one hundred and ten miles from its mouth, and at that distance reach an elevation of 650 feet above the present sea-level. Although fossil marine shells are only found for some forty miles from the sea, there is no doubt that the beds farther inland are a direct continuation of those holding fossils and mark the limits of the ancient sea-level. As the exploration of the Big river was not continuous, it is impossible to say to what distance inland the marine deposits extend. For the first forty miles from its mouth the river flows between steep banks of clay, capped with sand holding numerous fossils. On the Great Whale river stratified deposits extend inland a distance of thirty miles to beyond the forks. Above this the river passes for several miles through a deep narrow gorge on its way down from the interior plateau. Any stratified deposits which might have existed in this gorge have been washed away, and the only traces of such are isolated patches of fine sand clinging to the rocky sides in protected positions. The highest of these are about 100 feet above the river or, roughly, 600 feet above the sea. Terraces up to 300 feet elevation flank the rocky hills in a number of places along the northern coast. At the mouth of the Clearwater river on Richmond gulf a series of fine sandy terraces are seen, the highest being about 300 feet above the water.

The first portage on the route from Richmond gulf to Clearwater lake passes up a wide valley over old sea beaches facing the gulf; the highest of these on a level with a small plain is 450 feet above the sea. Beyond this for ten miles up the small stream followed by the route there are terraces cut in stratified clays and sands that rise in the highest 160 feet above the river, or 675 feet above the present sea-level. Beyond this line the surface material is unstratified till.

From the above it will be seen that the Pleistocene elevation of the western side of Labrador was nearly uniform from the south end of Hudson bay to Richmond gulf, with a maximum elevation of 675 feet toward the north.

According to Dr A. S. Packard,* raised beaches and terraces are found along the Atlantic coast from the strait of Belle Isle to Hopedale. These are seldom or never more than 200 feet above the sea, or less than one-third of the elevation of the terraces on the western side.

If the theory that the greatest elevation conformed with the areas of greatest ice accumulation, the ice-cap on the western part of Labrador must have been much thicker than that on the eastern portion. This agrees with the state of glaciation observed by Dr Bell † along the northern Atlantic coast, where he reports that the upper parts of the high Coast range form sharp serrated peaks, covered with undisturbed rotted rock, and that evidence of glacial action is only seen in their lower valleys.

* The Labrador Coast, pp. 306–310.

† Report of Progress, Geol. Surv. Canada, 1882–'83–'84.

The second paper read was:

HEIGHT OF THE BAY OF FUNDY COAST IN THE GLACIAL PERIOD RELATIVE TO SEA-LEVEL, AS EVIDENCED BY MARINE FOSSILS IN THE BOWLDER-CLAY AT SAINT JOHN, NEW BRUNSWICK

BY ROBERT CHALMERS

Remarks were made by Mr Warren Upham as follows:

These fossiliferous beds with till above and below them were doubtless formed close to the ice-front, which, as Mr. Chalmers has shown, probably rested on the neighboring hills of this coast, temporarily receding to them and thence readvancing a short distance into the sea. That the ice-sheet was near is implied by the abundance of the shells of *Yoldia* (*Leda*) *arctica*, which is now found only in Arctic seas and thrives best, according to Baron de Geer's observations in Spitzbergen, near the mouths of streams of very silty water discharged from glaciers.

The paper is printed as pages 361–370 of this volume.

The following paper was read by title:

THE ABANDONED STRANDS OF LAKE WARREN

BY ANDREW C. LAWSON

This paper is incorporated in the Twentieth Annual Report of the Geological and Natural History Survey of Minnesota, 1891, pages 181–239.

The next paper was read by the author, but not submitted for publication:

THE PLEISTOCENE HISTORY OF NORTHEASTERN IOWA

BY W J MCGEE

In the discussion of the paper remarks were made by R. D. Salisbury, C. R. Van Hise, Warren Upham, Robert Bell, and Mr J. M. Macoun, a visitor. The paper is embodied in the Eleventh Annual Report of the United States Geological Survey, 1889–'90, pages 189–577.

The last paper of the morning session was:

ESKERS NEAR ROCHESTER, NEW YORK

BY WARREN UPHAM

This communication is published in the Proceedings of the Rochester Academy of Science, volume ii, pages 181–200.

At the close of the reading of this paper a recess was taken until 2 o'clock p. m.

On reassembling at 2 o'clock the following communication was read:

COMPARISON OF PLEISTOCENE AND PRESENT ICE-SHEETS

BY WARREN UPHAM

The paper provoked a spirited but pleasant discussion, the chief point of division being the evidence as to the existence of man in America during glacial time. Remarks were made by W J McGee, A. R. C. Selwyn, G. F. Wright, R. D. Salisbury and the author. The paper is printed as pages 191–204 of this volume.

The next paper was as follows:

THE SUPPOSED POST-GLACIAL OUTLET OF THE GREAT LAKES THROUGH LAKE NIPISSING AND THE MATTAWA RIVER

BY G. FREDERICK WRIGHT

During the early part of last September, in company with Judge C. C. Baldwin, of Cleveland, D. C. Baldwin, of Elyria, and Professor Albert A. Wright, of Oberlin, and while engaged in the work of collecting fragments of the rock in place along the line of the Canadian Pacific railroad from the Sault Ste Marie to Ottawa to aid in identifying the glacial bowlders of Ohio, we turned aside for a few days to study the evidence which attracted our attention in support of Mr Gilbert's hypothesis that upon the first melting back of the ice of the glacial period the main part of the water of the great lakes ran for a while from Lake Nipissing by way of the Mattawa river into the Ottawa. This theory was, I believe, first presented by Mr Gilbert at the meeting of the American Association for the Advancement of Science at Toronto in August, 1889. The substance of his address upon that occasion was published in the Sixth Annual Report of the Commissioners of the State Reservation at Niagara (pages 61–84) and reprinted in the Smithsonian Report for 1890 (pages 231–257).

The general facts suggesting such an outlet are those connected with the northerly depression of land known to exist at the close of the glacial period, and revealed in the familiar phenomena of the so-called Champlain epoch. The subsidence at Montreal, as shown by the marine shells resting upon glacial deposits, was a little over 500 feet, while in the valley of Lake Champlain it was considerably less, and in the latitude of New York city very much less still, if it had not wholly disappeared. It is difficult to determine from direct evidence at hand what was the subsidence in the region of the great lakes, though it is evident from Mr Upham's report upon the shore-lines of Lake Agassiz, from the investigations of Mr Gilbert and Mr Spencer upon the raised beaches about Lake Ontario, and from the various reports upon the old shore-lines north of Lakes Huron and Superior, that this differential northern subsidence characterized the whole interior basin east of the Rocky mountains. These facts, coupled with the known relative depression of the col between Lake Nipissing and the Mattawa river, naturally created confidence in Mr Gilbert's theory that the outlet of the great lakes by way of this col was once a reality, for the difference of level between Lake Erie and the col at

North bay, Ontario, is but little more than 100 feet, Lake Nipissing being, as we make it, but 61 feet higher than Lake Huron, 66 feet above Lake Erie (water works, south margin of North bay), and Trout lake, at the head of the Mattawa river, but 20½ feet above Lake Nipissing, while the col between is nowhere more than about 25 feet above Trout lake. A differential depression, therefore, of 150 feet, as between North bay and Niagara, would now divert the waters of the lakes by the Ottawa river, while the passes between the Mattawa and Lake Ontario are all of a considerably greater height. From these facts it was natural to expect that such an outlet existed.

We did not have time to trace the whole line of the supposed outlet, but the following observations upon the local facts seemed to be sufficient to add greatly to our confidence in Mr Gilbert's theory, if they do not, indeed, positively prove it. The col between Lake Nipissing and Trout lake, extending from one lake to another, a distance of two or three miles, is wholly occupied by a level swampy tract, as already said, not more than 25 feet above Trout lake and unobstructed by any continuous ridge of rocks or higher land. On the north this swamp is bordered by an extension of an old beach-line of Lake Nipissing, constituting a clearly defined terrace carrying a great abundance of well-rounded pebbles and extending from lake to lake at a height of about 50 feet above the swamp referred to. This beach borders the more elevated region which rises to the north. Upon the south side of the passage between the two valleys the indentations are so extensive and irregular that we did not have time to trace the corresponding shore line, but this would seem sufficient to show that the water of the lakes for some time stood between Lake Nipissing and Trout lake at such a relative level that if the way down the Mattawa and Ottawa were free from obstruction it must have poured in that direction in torrential volume. If such a torrent poured down the Mattawa the effects should show themselves in a pronounced manner in a bowlder terrace at the junction of the Mattawa and Ottawa rivers, which is about 40 miles distant (46 by railroad), and according to the railroad survey 95 feet lower in level, which is about 80 above the river, making the difference of water levels (that is between the top of the Nipissing-Trout lake terrace and low water at Mattawa) of about 225 feet (95 + 50 + 80).

Upon going down to the mouth of the Mattawa river we found an enormous bowlder terrace far exceeding our expectations, which it would seem difficult to account for on any other theory than that of the temporary existence at the close of the Glacial Period of Gilbert's supposed torrential current of water from the Great lakes. The bowldery delta terrace begins on the south side of the Mattawa about three-quarters of a mile above the junction of the rivers and extends a somewhat less distance down the right bank of the Ottawa. It enlarges about the middle of this distance and pushes out as a bar almost entirely across the Ottawa river, making deep slack water above and turbulent rapids for a long distance below. The terrace in this lower angle over the space mentioned consists entirely of bowlders and well-rounded pebbles, which completely cover the surface and apparently form the whole body of the terrace. The bowlders range in size from a few inches up to 30 feet in diameter, and the terrace is level-topped, the height above the river being, according to our estimate, about 80 feet. A short distance back from the Ottawa river there is a well-marked river channel cutting across that portion of the deposit which projects as a bar into the Ottawa river. This is the line of the flow of the Mattawa river when it joined the Ottawa about a mile below

its present mouth. The bed is well-defined, with its bottom about 25 or 30 feet above the present river and with bowlders of the largest size upon each side.

Upon the north side of the Mattawa river for a mile or more above its junction there is a slender but well-defined terrace of the same height with that upon the south side, but consisting of fine material, presenting an area which has naturally been chosen for the cemetery and for a race-course. On the south side also the great bowldery delta terrace shades into finer material higher up the stream.

We followed up the Mattawa river a distance of about 8 miles, to the vicinity of Eau Claire. Though not able to study the region so carefully as we would have liked, everything so far as we could observe was favorable to the theory of its having been the temporary channel of a great stream of water. Terraces exist here and there, such as would be expected, and the descent of the channel at the portage of Plain Champ would aid in producing that final plunge in the descending stream required to produce the effects described at the junction a mile or more below.

The only theories worth considering in accounting for these phenomena are that this collection of bowlders is of the nature of a moraine modified by temporary local floods which came down the Mattawa upon the melting of the ice, and that of Mr Gilbert, that the torrent of Niagara was for a time diverted down this trough.

The moraine theory would seem untenable from the position of the material. It is not in position for a moraine moving down either the valley of the Ottawa or of that of the Mattawa. It is in fact midway between the two, upon the lower angle of their junction, and runs up the Mattawa valley in a way to indicate the predominant influence of rushing water coming down that valley. The position and character of the bowlder terrace and its relation to the terrace upon the opposite side of the Mattawa is strictly analogous to that which I have described* as occurring at Beaver, Pennsylvania. The accumulation of bowlders is also strictly analogous to that at Pocatello, Idaho, where the Port Neuf valley opens out into the Great Snake River plain, and described by me on pages 235–236 of my recent work, "Man and the Glacial Period." In the case of the Beaver terraces we have to account for them by the vast floods at the close of the Glacial Period, but the accumulation is as nothing in comparison with that at Mattawan. At Pocatello, however, some time after my collection of the facts, the publication of Mr Gilbert's monograph upon Lake Bonneville made it clear that the overflow of that great lake led down the Port Neuf river, and that for a period of 25 years the volume of the flow was comparable to that of the Niagara, and the results are, as we have said, closely analogous to those at Mattawan and almost equal in their extent. The further prosecution of inquiries through the whole length of the valley of the Mattawa will, however, by some be thought necessary to complete the verification of this theory; but for one I expect most confidently the evidence will be forthcoming when attention is sufficiently directed to the region.

Professor Wright's paper was discussed by the President and by Robert Bell. Dr Bell said:

I have been over the ground referred to by Professor Wright and Mr Gilbert. I think Professor Wright's hypothesis interesting as a suggestion, but do not consider that sufficient evidence has yet been offered to make it anything more than that. The matter has not been sufficiently investigated to enable us to come to

* Bull. 58, U. S. Geol. Survey, p. 77.

any acceptable conclusion. The whole course of the supposed outlet should be examined before it can be asserted that some objections fatal to the theory do not exist. The lines of bowlders to the northward of Trout lake, which have been referred to, might belong to moraines and not to lacustrine terraces, which in any case would only prove a former eastward extension of Lake Nipissing.

Lake Huron is 582 feet above the sea and Lake Nipissing 637 feet, or 55 feet higher. As the ground is low between Lake Nipissing and Trout lake, if Lake Huron were only a little more than 55 feet higher than at present its waters might have flowed down the Mattawa river at the time supposed by Professor Wright, provided the relative levels of the whole region were the same then as now; but this was unlikely to have been the case.

The valley of the Mattawa appeared to be only large enough for a river of the small size of the present stream. At the outlet of Trout lake the ground is high and the river passes through a narrow opening. Again, from the outlet of Turtle lake to Lake Talon the stream runs in a very contracted valley, which, speaking from memory, I do not think gives indication of having afforded passage to a larger body of water. Further down in the neighborhood of the south branch, the Amable du Fond, the valley appeared to be quite contracted at several points.

I did not think that the bowlder-covered field or plateau on which Mattawa village is built could be cited as evidence in support of the present theory. Many similar fields were to be found along the Ottawa. The ridge of bowlders, pointing northward, which juts out into the Ottawa river at the mouth of the Mattawa, is of morainic origin and has probably been left by a glacier which came down the north-and-south stretch of the Ottawa just above this locality, or from one of the tributary valleys on the opposite side of that river. Corresponding ridges of bowlders, transverse to the current, formed similar points projecting into the Ottawa in many places all along its course. Some of them ran completely across the bed of the stream, as, for example, the one near Kettle island, only a few miles below Ottawa city, which at low water entirely obstructed navigation except at one narrow gap. All these I regard as having been left by glaciers descending from the north-and-south valleys, which cut through the rocky hills to the northward and fall into the Ottawa at right angles. I have described them in the chapter on Surface Geology written for Sir W. E. Logan, in the *Geology of Canada*, 1863.

If, in comparatively recent geologic times, the valley of the Ottawa river, from the junction of the Mattawa to its mouth, had acted as a channel for the conveyance of a much larger body of water than the present stream, we should see abundant evidence of the fact at many places on its course, but such evidence appears to be wanting. Along its lower reaches for perhaps 200 miles above the mouth clay banks of moderate elevation rise from high-water mark, and from their brink level tracts extend in many places for miles to the southward. The difference between the annual high and low water marks in the Ottawa is a little over 20 feet. During the period of high water the river cuts into the foot of the clay banks and so produces irregular widenings of the stream at the flood line. There is no sign of any former erosion of these clay flats by a higher level of water. In the vicinity of the rapids and falls of the Ottawa evidence also appears to be lacking of the former passage of any larger body of water than at present.

In reference to the terraces around Lake Huron I will say, in connection with the question, that along the north shore of that lake old beaches are to be seen almost everywhere up to a little over fifty feet above its present level, but that they have only been noticed at greater elevations in a few places, such as near

Parry sound, referred to by Mr Gilbert, and also at Wikwemikong on Manitoulin island. More than forty years ago Mr Sandford Fleming, of Ottawa, wrote an account in the Journal of the Canadian Institute of the terraces around Nottawasaga bay, which had also been described by Professor Chapman; and I have made profiles of the country to the southward of Georgian bay from lines of spirit-levels which I ran. These showed lacustrine terraces at almost every height up to some 200 feet, but in the present state of our knowledge these facts might prove nothing in reference to former outlets of Lake Huron, since the whole of the surrounding area may have been slightly canted instead of having been uniformly elevated.

These were some of the unanswered difficulties which have presented themselves to my mind while Professor Wright was reading his paper, and I think that, apart from the upsetting of all the calculations of geologists based on the facts presented by the Niagara gorge, they are sufficient to justify me in not accepting the Professor's hypothesis until further investigations have been made.

The next paper was read for the absent author by Mr W J McGee:

ON CERTAIN FEATURES IN THE DISTRIBUTION OF THE COLUMBIA FORMATION ON THE MIDDLE ATLANTIC SLOPE

BY N. H. DARTON

Remarks upon the paper were made by R. D. Salisbury, Warren Upham and W J McGee.

In the absence of the author the next paper was read by R. W. Ells:

NOTES ON THE GEOLOGY OF MIDDLETON ISLAND, ALASKA

BY GEORGE M. DAWSON

Middleton island is situated opposite Prince William sound, in that part of the north Pacific which on some maps is named the gulf of Alaska. It is distant about sixty-four miles from the mouth of the Copper river, the nearest part of the mainland coast, and some fifty-five miles from the nearest points of any other land—these being parts of the shores of Kaye island, Alaganik island and Montague island. The three islands mentioned are all adjacent to the coast of the mainland and separated from it by comparatively narrow waters. They lie in northeast, north and northwest bearings respectively from Middleton island, which thus stands alone and not far from the edge of the hundred-fathom bank or margin of the continental plateau.

Mr J. M. Macoun was landed on this island on June 15, 1892, by H. M. S. *Nymphe*, and occupied the few hours at his disposal there in making a paced survey around the entire shore of the island, either on the beach or along the summit of the low bordering cliffs when walking on the shore itself proved to be impossible. He collected some specimens of the material of which the island is composed and made a few notes upon it, determining the heights of the cliffs, etc, by means of an aneroid barometer.

Mr Macoun does not profess to be a geologist, but on his return he submitted his specimens to me, and it was at once apparent that these represented a true till or bowlder-clay. The position of this island—lying as it does so far to seaward—

rendered this fact interesting, and some examinations of this bowlder-clay were made. It is proposed to give the results of these examinations.

Knowing that Dr W. H. Dall had visited the island some years ago, I wrote to him, after having examined the specimens, to ask whether any account of its geology had been previously published, and learned that a very brief note, based on Dr Dall's observations made in 1874, had lately been printed in Bulletin No. 84 of the U. S. Geological Survey, pages 259–260. Dr Dall further obligingly supplied me with an early copy of this publication, but the facts now ascertained appear to throw a wholly new light on the structure and geologic age of the island.

Mr Macoun has furnished me with a very clear general description of the island, based on his survey of it, which it is proposed to quote as introductory to the few remarks based on my study of the specimens. He writes:

"Middleton island is a little over five miles in length and a mile and a quarter in breadth at its southern and wider end. At its northern extremity it narrows to a low sandy point, from which a spit extends northward more than two miles. This spit is bare at low tide. For more than ten miles off the southern end breakers are to be seen at all stages of the tide, and at low tide several rocks or shoals show above water.

"About the center of the west side of the island there is good anchorage, and from there to the southern end there is no beach, the cliffs rising perpendicularly from the water to a height of about 100 feet. From 100 to 300 yards back from the edge of the cliff the ground is level and boggy, but it then rises abruptly between 25 and 40 feet. There is, in fact, here a distinct terrace cut back in the material of the island, at a height of 100 feet above sea-level. The surface of the island slopes gradually up from the eastern side to the high ground on the west, so that the greater part of the water that falls upon the island runs off on the eastern side. Not even the smallest stream is to be seen, but everywhere there is a constant trickling of water over the cliffs, and so soft is the material of which the island is composed, that on the eastern side it is being gradually worn away and forms a steep incline from the summit to the water.

"The cliffs on this side are from 30 to 50 feet in height, and from their summit it can be seen that the rock or general material of the island extends for some distance out from the shore, the slope being much less after the level of the sea is reached.

"For about two miles along the eastern shore of the island the beach is strewn with pebbles and small limestone bowlders. At the northern end and for about two miles along the northwestern shore, the level rises but a few feet above the sea and the beach is composed of sand only. For nearly a mile beyond this, toward the south, there are a good many bowlders along the shore, consisting of granites, as well as black argillite. Just opposite the anchorage a band of gravel not more than two feet in thickness was noticed running along the cliffs, and there may be more bands or beds of the same material elsewhere, as no special importance was attached to these at the time and they were in consequence not looked for or precisely noted, and none of the cliffs along the southern half of the island were seen from the water. In my notes, the material of which the island appears otherwise to be entirely composed was called a soft conglomerate, and the stones contained in it are often as large as the head or larger.

"These seen along the shore appear to be derived, at least for the most part, from the wearing away of the general material of the island, and vary in size from minute pebbles to large ones a foot or more in diameter. This action must be very rapid, for when there is no true pebbly or sandy beach, which is the case for about three miles of the shore line, the waves wash in against the actual base of the cliffs, which are in several places undercut. For about one and a half miles along the middle part of the island, on the east side, where the cliffs are from 10 to 25 feet high only, there is no beach, but the characteristic rock of the island extended here at half-tide from 10 to 20 yards out from the base of the cliff as a level floor. The sea was nearly calm at this time, but the water was discolored by earthy matter for some distance from the shore; and when wet, along the edge of the sea the material is not only very slippery, but so soft that it may be rubbed away by the hand. About two miles from the northern end of the island one of the officers of the *Nymphe*, who had been walking along the shore and had come to a point he could not pass, had climbed up the cliff by cutting places for his feet with his knife, and when I reached this place I ascended to the summit of the cliff in the same way."

The component material of Middleton island, as represented by the specimens brought back by Mr Macoun, is, as already stated, a good typical bowlder-clay or

till, of rather dark, bluish-gray color, and somewhat unusually hard and compact. It shows no sign of oxidation by weathering, and in the actual specimens received is packed with small stones which vary in size from about an inch and a half in diameter downward. These lie in all positions, and there is no apparent stratification or lamination whatever, though here and there small parts of the whole appear to be more arenaceous than the rest. None of the stones are perceptably facetted, nor on these seen can any distinct striation be observed. They are either subangular or fairly well-rounded in shape, and the surfaces of a few of them are so smooth as to be described as polished. It is apparent, in fact, that they represent water-rounded material.

The stones themselves consist almost exclusively of a hard, fine-grained, nearly black material, which has not been microscopically examined in thin sections, but appears to be undoubtedly a rather indurated argillite, resembling rocks seen by the writer on several parts of the Alaskan coast, and which, merely from their lithologic analogy with similar rocks on the better-known coast of British Columbia, may represent what has been named the Vancouver Group, of Triassic Age.

The material also contains rather numerous fragments of shells, but all so much broken in the specimens actually received as to be impossible of exact determination. One small piece of a ribbed shell appears, however, to represent a small specimen of *Cardium blandum*. Several fragments, when microscopically examined, were found to be slightly rounded on the broken edges, while others were quite angular. The whole mass of the clay is more or less calcareous, effervescing freely when an acid is applied. Though very hard when dry, fragments broken from the inner surfaces of the specimens of bowlder-clay when placed in water partially break up, and with the aid of agitation and occasional slight pressure applied to the harder lumps the whole was easily and completely disintegrated.

After removing the larger stones from about an ounce of the material, the residue was subjected to a series of decantations at different intervals of time, by means of which its constituents were separated in accordance with their size and specific gravity, the *modus operandi* being the same as that employed in previous investigations of bowlder-clays.*

A microscopic examination of the various samples thus obtained, showed this bowlder-clay to comprise a considerable proportion of very fine silty matter, of which the particles are nearly equal in size; also some formless argillaceous matter and a larger proportion of sand.

All grades of the sand proved to consist, to the amount of about one-third or one-half, of partially or well rounded grains of the dark argillaceous rock above referred to, while the remainder was chiefly composed of quartz, generally glassy and usually quite angular, though in part subangular or slightly rounded.

Two samples of this sand, of medium grade, were kindly examined in detail by Mr W. F. Ferrier, who states that, in addition to the argillite grains, the constituents of the coarser of these samples are as follows, in order of abundance:

Medium coarse.—Quartz, feldspar (no striated grains were observed), magnetite, a dark brown pyroxene (?), hornblende of various shades of green, brown mica, (biotite ?) and a very few grains of titanite.

Medium fine.—The same materials, but with mica and hornblende rather more abundant than in the last.

It may be added that the feldspar, pyroxene, hornblende, etc. are found in rather

* Bull. Chicago Acad. Sci., vol. i, no. vi.

small quantity, the impression conveyed being that the sand cannot in any large part be considered as directly derived from crystalline rocks. In the coarsest specimens of sand resulting from the mechanical analysis of the bowlder-clay the constituent grains were easily separable by the unaided eye, and among them were found small fragments of shells and a number of foraminifera. Of these a small collection was picked out and mounted, comprising about two dozen individuals, and representing perhaps half the number present in about an ounce of the material.

These have been examined by Mr J. F. Whiteaves, who reports all the specimens but three to be referable to *Polystomella striatopunctata*, Frichtel and Moll, while of the remaining specimens one is *Pulvinulina karsteni*, Reuss, another probably *Nodosaria* (*Glandulina*) *lævigata*, D'Orb., and the third not determinable, being encrusted and badly worn.

The *Polystomellæ* are rather small and depauperated in appearance, resembling in this respect those found in the upper part of the gulf of Saint Lawrence,* where the water becomes distinctly less saline than normal, but the collection so far examined is quite too small to warrant any theorizing on this fact.

In examining the medium grades of sandy material under the microscope numerous fragments of sponge spicules were noticed. These were generally straight, simple and tubular, but, so far as observed, never perfect. No diatomacæ were seen, though more extended and minute search might probably lead to this discovery.

In containing broken shells and other forms of marine life, the bowlder-clay here described resembles that of some parts of the Queen Charlotte islands already described by the writer.† The available evidence is, however, insufficient to enable us to refer the deposit of bowlder-clay of which Middleton island is composed to its proper place in the sequence of events of the glacial period, for elsewhere on the coast, and probably generally, there are two distinct bowlder-clays, which can only be separated with certainty when both are seen. This bowlder-clay may have been formed as a marine bank in proximity to the fronts of great glaciers debouching along the coast of the mainland to the northward, upon which detached icebergs grounded from time to time.

The interstratified layer or layers of pebbly material observed by Mr Macoun might thus be explained, and it appears further to be borne out by the description by Mr Dall, whose attention seems to have been more particularly directed to evidences of bedding, and who writes:

> "The island is composed of nearly horizontal layers of soft clayey rock, containing many pebbles and even bowlders of syenite and quartzite, some rounded and others of angular shape. Above the claystone is a layer of gray sand covered with several feet of mould and turf."‡

It is perhaps, however, on the whole more probable that this projecting mass of bowlder-clay forming Middleton island represents a portion of a morainic accumulation formed at or near the seaward edge of an ice-field derived from the adjacent mainland, and which pushed southward or in a direction at right angles to that of the average trend of the nearest continental coast.

The broken character of the shells seems to favor the belief that the material was ploughed up from the sea bottom and greatly disturbed, rather than to show that it represents merely a bank upon which glacial débris was occasionally discharged. Such a bank might probably be from time to time poached up by

* See Canadian Naturalist, 1870, p. 172.

† Quart. Jour. Geol. Soc., May, 1881. Report of Progress, Geol. Surv. of Canada, 1878-'79, p. 91 B.

‡ Op. supra cit., p. 260.

grounding ice, but this alone would appear to be scarcely sufficient to explain the always broken appearance of the mollusks in the specimens actually to hand.

The distance from the border of the mainland (about 55 miles) would seem to indicate that it represents a portion of the morainic deposits formed at the outer edge or along the retreating front of that part of the continuation of the Cordilleran glacier which is believed to have occupied the highlands of the corresponding part of the Alaskan coast during the first and most important period of glaciation.*

It will be noted that the island lies opposite an extensive indentation in the general coast line, marked by Prince William sound and also by the Copper River valley, and it is therefore possible that the corresponding portion of the great glacier here stretched further seaward than elsewhere. The water between the mainland coast and Middleton island is not very deep, varying, according to the few soundings shown on the chart, from 30 to 50 fathoms. It is therefore quite probable that a glacier-sheet moving outward from the land may still have borne upon the sea-bed with sufficient weight to produce the effects above alluded to, even were the relative elevations of sea and land the same as those of to-day. There is, however, so much reason to believe that very extensive changes in levels have occurred in the region during and subsequent to the glacial period, that it is not safe to assume that the relative levels were identical with those now existing. It is reasonably certain that the island, composed of such relatively soft material, and exposed as it is with few protecting beaches to the full force of denudation exerted by a stormy ocean, has not for any very protracted period, from a geologic point of view, stood at its present level. Mr Macoun's description of the western side of the island in fact distinctly indicates the existence there of a well-marked terrace, cut back at a height of about 100 feet above the present sea-level. Whether this actually represents, in a modified form, that pause in elevation which the coast further south seems to have experienced during the closing events of the glacial period (there at an elevation of about 200 feet) † it is difficult to say; but it indicates, with scarcely any doubt, one stage in that general and last process of elevation. The unoxidized character of the bowlder-clay itself seems to show that it can never for a very prolonged period have been subjected to subaërial agencies.

In Dr Dall's observations on Middleton island, already quoted, the following statements are in conclusion made:

> "Below the sea-level some of the rock appeared to be quartzite in place and very hard. Whatever its nature, it extends in reefs and shoals to a distance of several miles from the island in different directions. No fossils were found in the claystone, but from its character it was suspected to be post-Miocene and possibly Pliocene" ‡

Respecting the existence of a quartzite basis of the island, Dr Dall writes doubtfully as above, while Mr Macoun did not note any such underlying rock in following the shores. It would appear to be very probable that the surrounding reefs or shoals are merely the higher parts of a plane of marine denudation or banks thrown up upon such a plane, which now surrounds this rapidly diminishing island and corresponds with its original size under the existing relative levels of sea and land in the region. As to the age of the material composing the island itself there seems to be no room for doubt that this is Pleistocene and referable to the Glacial Period.

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* Later Physiographical Geology of the Rocky Mountain Region, etc: Trans. Royal Soc. Canada, vol. viii, sec. iv, map 4.

† Ibid, p. 54.

‡ Op. supra cit., p. 200.

Remarks upon Dr Dawson's communication were made by C. W. Hayes.

The next communication was read by title:

TWO NEOCENE RIVERS OF CALIFORNIA

BY WALDEMAR LINDGREN

The paper is printed as pages 257–298 of this volume.

The following paper was read by the author:

THE LAURENTIAN OF THE OTTAWA DISTRICT

BY ROBERT W. ELLS

It was discussed by F. D. Adams, C. R. Van Hise, A. R. C. Selwyn and the author. It is printed as pages 349–360 of this volume.

The last paper of the day was—

THE CONTACT OF THE LAURENTIAN AND HURONIAN NORTH OF LAKE HURON

BY ROBERT BELL

A full synopsis of this paper will be found in the American Geologist for February, 1893, pages 135–136.

Before adjourning it was announced that the Fellows were invited to the annual dinner of the Logan Club at the Russell house, Thursday evening.

Session of Friday, December 30

The President called the Society to order at 8.15 a. m.

The Auditing Committee reported that the accounts and report of the Treasurer had been found correct. The report of the committee was accepted and the committee discharged.

The following letter was read by the Secretary:

Boston Society of Natural History,
Boston, Massachusetts, December 27, 1892.

Dear Sir: I have the honor of extending the cordial invitation of the Boston Society of Natural History to the Geological Society of America to hold its next winter meeting in Boston, at our building. I am pleased to assure you that if the geologists come to Boston one year from this time they will receive a cordial welcome.

Most respectfully, William H. Niles, *President.*

To Professor H. LeRoy Fairchild,
Secretary of the Geological Society of America.

A telegram from Sir J. W. Dawson, the President-elect, in response to one sent him notifying him of his election, was received, and read at a later hour during the morning session.

The President announced that the summer meeting would be held at Madison, Wisconsin, the precise date in August to be announced later.

The annual address of the President was read from the chair:

CONTINENTAL PROBLEMS

BY G. K. GILBERT

The address is printed as pages 179–190 of this volume.

The first paper of the program was—

THE ARCHEAN ROCKS WEST OF LAKE SUPERIOR

BY W. H. C. SMITH

Mr Smith,* a member of the Geological Survey Department of Canada, was introduced by R. W. Ells. The paper was discussed by C. R. Van Hise and A. R. C. Selwyn. It is printed as pages 333–348 of this volume.

The second paper was—

RELATIONS OF THE LAURENTIAN AND HURONIAN ROCKS NORTH OF LAKE HURON

BY ALFRED E. BARLOW

Remarks were made by C. R. Van Hise. The paper is printed on pages 313–332 of this volume. It was read under the title "On the Archean of the Sudbury mining District."

A recess was taken until 2 o'clock. When the Society reconvened the following paper was read for the absent author by Mr W J McGee:

THE WORK OF THE UNITED STATES GEOLOGICAL SURVEY

BY J. W. POWELL

The communication was illustrated by samples of the maps published and projected by the Survey. Remarks were made by A. R. C. Selwyn and B. K. Emerson. The paper is printed in Science, volume xxi, number 519, pages 15–17.

* Soon after the adjournment of the meeting came the sad announcement of the death of Mr. Smith. To his activity was in no small measure due the success of the Ottawa meeting, and, indeed, his death may be said to have been partly due to his persistent efforts, exerted even in the face of his physician's warning.

The next paper was—

GEOMORPHOLOGY OF THE SOUTHERN APPALACHIANS

BY C. WILLARD HAYES AND M. R. CAMPBELL

Remarks were made by W J McGee. This paper will be published in the National Geographic Magazine.

The Society then, at 3.30 p. m., adjourned until the evening, in order that the Fellows might be able to accept the invitation to a reception tendered the Society by Her Excellency The Lady Stanley of Preston, at Government house, at 4 o'clock.

Evening Session of Friday, December 30

The Society was called to order at 8 p m, Mr F. D. Adams in the chair.

The first communication was—

NOTES ON THE GOLD RANGE IN BRITISH COLUMBIA

BY JAMES MCEVOY

Mr McEvoy, who is a member of the Geological Survey Department of Canada, was introduced by H. M. Ami. Remarks upon the paper were made by A. E. Barlow.

The second paper of the evening session was—

THE IMPORTANCE OF PHOTOGRAPHY IN ILLUSTRATING GEOLOGICAL STRUCTURE

BY R. W. ELLS

The paper was illustrated with a series of large photographs, and was discussed by B. K. Emerson, F. D. Adams and Mr J. Lainson Mills, a visitor.

In the absence of the author of the following two papers, the first was read by Mr U. S. Grant and the second by Mr J. S. Diller:

SOME MARYLAND GRANITES AND THEIR ORIGIN

EPIDOTE AS A PRIMARY COMPONENT OF ERUPTIVE ROCKS

BY CHARLES ROLLIN KEYES

These two papers were discussed by F. D. Adams. They are printed as pages 299–312 of this volume.

The next two papers were read by the authors, being, on account of their relationship, placed in juxtaposition:

CRETACEOUS AND EARLY TERTIARY OF NORTHERN CALIFORNIA AND OREGON

BY J. S. DILLER

This paper is printed as pages 205–224 of this volume.

THE FAUNAS OF THE SHASTA AND CHICO FORMATIONS

BY T. W. STANTON

This paper is printed as pages 245–256 of this volume.

President Gilbert assumed the chair, and the following paper was read:

THE HURONIAN VOLCANICS SOUTH OF LAKE SUPERIOR*

BY C. R. VAN HISE

[*Abstract*]

South of Lake Superior are extensive areas of Huronian rocks, consisting of a succession of basic lava flows, with interstratified contemporaneous fragmentals. Associated with these are occasional porphyries.

Petrographically the volcanic series includes porphyrite, augite-porphyrite, amygdaloid, devitrified glass, flowage breccia, and greenstone conglomerate. Included under the latter term are agglomerates, tuffs, mingled tuff and lava, and true detrital conglomerates, the material of which is chiefly derived from the volcanic series.

The porphyrites and augite-porphyrites are fine-grained, dense, and frequently show, when weathered, a very curious spheroidal parting; also at times they pass into flowage breccias.

The amygdaloids vary from pumiceous or scoriaceous rocks into those in which the amygdules are rare, until finally the porphyrites are reached. Like the porphyrites, they show at times a spheroidal parting or brecciation, and not infrequently in the spheroidal phases, each of the spheroids is dense and non-amygdaloidal on one side and distinctly amygdaloidal upon the other. Moreover, the amygdaloidal portions are all on the upper sides of the blocks. It would seem that while the rock was still viscous it must have cracked, and that before solidification occurred, in each block the amygdaloidal cavities rose to the upper part.

The amygdules are chlorite, feldspar, epidote, and quartz, including chalcedony and jasper. In the more open amygdaloids the amygdules are sometimes as much as 8 or 10 inches in diameter. The ferruginous quartz, known as jasper in these amygdaloids, is so remarkably like the jasper of the iron-bearing formation south of Lake Superior that it was at first thought that these are inclusions caught in the lava, but a closer study shows their undoubted amygdaloidal character, since the

*Published by permission of the Director of the United States Geological Survey.

amygdules are found of all sizes down to ordinary ones and with all gradations in color into the white chalcedony and quartz. As the chert and jasper formation in one of the districts rests directly upon the amygdaloid it is believed that the jasper of the ore formation and that in the amygdaloïd are secondary rocks, formed simultaneously, as has been advocated by Irving and myself in reference to the major part of the ore formations of the Lake Superior region.

The term greenstone-conglomerate, rather than agglomerate, is used because this latter implies a definite theory of origin. A study of these rocks, in the field and under the microscope, shows undoubted gradations from rocks which are true detritals to those which are tuffs, from this to tuff and lava intermingled, and then to true lava flows, which are often brecciated. Probably also some of the rocks are true agglomerates. Some of the clastics are undoubtedly sub-aqueous ash-beds, from which there are gradations into the true detritals.

The interstratification of volcanics and detritals, combined with the lithologic similarity of the rocks, at once suggests a comparison between the Huronian volcanic series and the Keweenawan. There are, however, important differences. The Huronian volcanics are for the most part very much more altered than those of the Keweenawan. Many of thom have been sheared, and they then pass into crystalline greenstone-schists. The detritals, in common with the igneous rocks, have also frequently been metamorphosed into mica-schists, hornblende-schists, etc.

These volcanic series are known at various places south of Lake Superior, but the most extensive areas are at the east end of the Gogebic series, west of Gogebic lake, Michigan, and north of Crystal Fall, in the Michigamme district, Michigan. In the Gogebic area the volcanic group is 7,000 or 8,000 feet in thickness. The strata, in approaching the volcanic center, both from the east and the west, take a sudden swing to the south, showing a sinking of the formations about the volcanic foci, as a result of the loading of the earth's strata by a mountainous mass of volcanic material. Moreover, this great thickness of volcanic material stands as the equivalent in time to the iron-bearing formation of the west, which is, upon an average, not more than 700 or 800 feet thick. We thus are able to compare in this area the rate of deposition of a formation analogous to a limestone and a group of volcanic strata. Also the district gives an excellent illustration of the principle that in the pre-Cambrian rocks, lithologic character may be no guide as to age, for within a few miles we have a simple sedimentary series passing laterally into a volcanic series. If the two areas chanced not to be connected, there would be great temptation to infer that they are not contemporaneous.

Remarks upon Professor Van Hise's paper were made by W. H. C. Smith and W J McGee.

In the absence of the author of the following paper, it was read by Mr W J McGee:

ON TWO OVERTHRUSTS IN EASTERN NEW YORK*

BY N. H. DARTON

Last autumn I mapped the Helderberg and associated formations in New York for the geologic map of that state now in course of publication. In the western and central portions of the state these formations lie in the general, gently south-

* Extracted by permission from a report to Dr James Hall, State Geologist of New York.

dipping monocline, but in their eastward extension to the vicinity of the Hudson river they are traversed by small but steep and characteristic flexures of the northern prolongation of the Appalachians. Davis * has described two typical areas in this flexed belt, and in a memoir "On the Helderberg and associated formations of eastern central New York," to accompany the report of the state geologist for 1892, I shall describe the entire area from Schoharie to Ellenville. It is the purpose of this paper to exhibit two particularly interesting details of the structure of the region: one an overthrust fault near Rosendale, in the great cement region, and the other a composite overthrust west of South Bethlehem.

In Mather's report on the southeastern district of New York faults were proposed to account for nearly every prominent topographic feature in his district, but I find only a few faults in the Helderberg belt and these only of small amount and local influence. Mather's report is very meagre of details regarding the structure of this region, and his statements and sections are nearly all erroneous.

The relations of the overthrust near Rosendale are shown in the following figure :

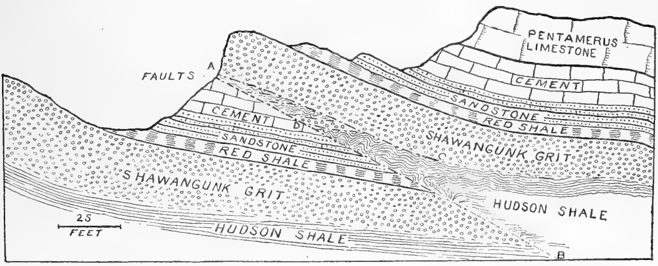

FIGURE 1.—*Cross-section of Ridge on south Side of Rondout Creek, at Rosendale, Ulster County, New York, looking North.*

The fault is on the eastern flank of the great corrugated anticlinal of the Shawangunk mountains, which pitches northward in the vicinity of Rosendale and involves the cement series and Helderberg formations. To the north the fault extends across the creek, through the village and up a depression, dying out in about two miles. To the south it soon runs out into the high, sand-covered terrace lying east of the Shawangunk ridges. Its maximum displacement is about 200 feet, which it attains at the village of Rosendale. The details of the fault are finely exposed in an abandoned cement quarry on the slope just south of the creek, and it is here that my section passes. The wedge of cement has been worked out for a length of 200 feet and the fault plane is the hanging wall of the quarry. Many minor features of slate wedges and crumpling are not represented in the figure, but I have shown at *D* a small wedge of grit which is faulted and cross-faulted into the main slate wedge at one point. The principal fault plane is along *A-B*, but there has been considerable movement along *A-C*, which has beautifully slickensided the surface of the grit. Cross-faults and minor crumples are irregularly intermingled

* The Little Mountains east of the Catskills: Appalachia, vol. iii, p. 20. The Folded Helderberg Limestones east of the Catskills: Harvard College, Bull. Mus. Comp. Zoöl, vol. 7, p. 311. Nonconformity at Rondout: Am. Jour. Sci., 3d ser., vol. xxvi, p. 389.

in the displacement, and I could not work out their relations. The relations below the cement wedge are not fully exposed, but there are scattered outcrops exhibiting the beds and their dips.

The overthrust west of South Bethlehem is in the gentle flexures near the region in which the Helderberg formations pitch up to the northward and extend to the northwestward out of the flexed belt.

The characteristics of this overthrust are the fault in the hard, massive beds of pentamerus limestone and an "underturned" flexure in the thin-bedded lower limestone, involving the subjacent soft Hudson slates.

The overthrust is exposed only on Sprayt creek, which it crosses at an old mill about three-quarters of a mile west-southwest of the village. Its trend is approximately north and south, but it does not appear to extend for any great distance. The relations at the mill are illustrated in the accompanying figures, in which the features above the broken-line portions of the sections are exposed in the bed and banks of the creek. It is unfortunate that the exposures are not more complete, but sufficient is in sight, I believe, to substantiate the interpretation I have given in the figures. Only the upper surface of the crumple is exposed in the limestone, but the greater part of the fault-plane is visible in the south bank of the creek

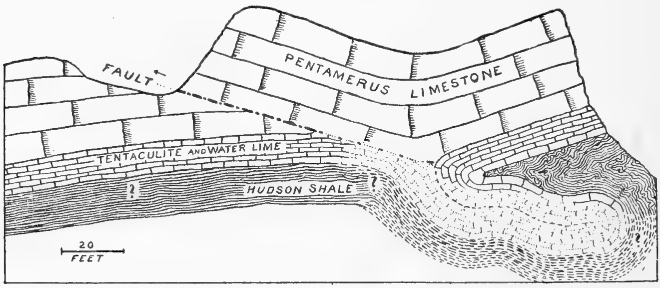

FIGURE 2.—*Cross-section of Overthrust West of South Bethlehem, Albany County, New York.*

Exposure on south bank of Sprayt creek, looking north (reversed).

above the dam. The overturned synclinal of slates and lowest limestone bed is clearly exposed in the base of the high bank on the south side of the creek, where the slate is seen to be excessively crumpled and its original bedding and cleavage planes obliterated. In the north bank, under the mill, the exposure is less extensive, but, as is shown in figure 3, essentially similar relations exist.

The mechanism of this overthrust is, I believe, not difficult to understand. I have represented the hypothesis of its development in the diagrams in figure 3: I, the first stage; II, the second, and the present conditions the third. The broken line on I indicates the line of weakness, the arrow the direction of thrust. The fault sheared diagonally through the hard, massive beds of pentamerus limestone, but the softer, thin-bedded, underlying limestones in moving forward with the thrust were not fractured, but folded downward and backward into the soft shales

below, as shown by the arrows in II. The fault truncated a small portion of a preëxistent arch of the lower limestones at *A* and carried them to *B*. The amount

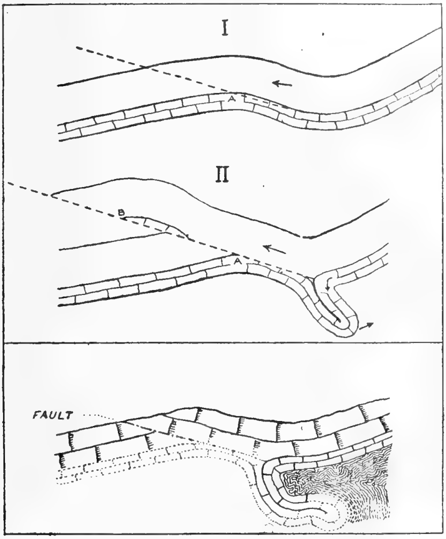

FIGURE 3.—*Overthrust on Sprayt Creek. Section on north Bank, looking North.*

I and II are hypothetical sections to illustrate two stages in the development of the overthrust.

of displacement was about 100 feet. The principal force in the overthrust was from the east, and almost horizontal in direction, unless the present low angles of fault and axial planes are due to subsequent backward tilting.

The last paper was read by title :

A GEOLOGICAL RECONNOISSANCE IN THE CENTRAL PART OF THE STATE OF WASHINGTON

BY ISRAEL C. RUSSELL

The President announced the completion of the scientific program.

The following resolutions were offered by Mr Frank D. Adams and unanimously adopted :

"*Resolved,* That the thanks of the Geological Society of America be tendered—

"To His Excellency the Governor-General of the Dominion of Canada for the cordial welcome which he extended to the Society, and to Her Excellency Lady Stanley for her very kind hospitality ;

"To the Logan Club for its invitation to the Society to meet in Ottawa and for its generous hospitality, and especially to its committee, consisting of Dr A. R. C. Selwyn, Dr R. W. Ells, Mr J. B. Tyrrell and Mr W. H. C. Smith, whose untiring efforts have so largely contributed to the success of the meeting;

"To the Royal Society of Canada, and to its committee, consisting of Dr J. G. Bourinot and Mr James Fletcher, for their invitation to meet in Ottawa, and for their kind attentions during the Society's visit;

"To the Clerk of the House of Commons, Dr J. G. Bourinot, for the ample suite of rooms which he has placed at the disposal of the Society during this meeting."

Remarks upon the resolutions were made by C. R. Van Hise, H. L. Fairchild, W J McGee, B. K. Emerson and G. K. Gilbert expressing the general sentiment that the Fifth Annual Meeting had been surpassingly successful and pleasant.

With a few appropriate remarks the President declared the meeting closed.

Register of the Ottawa Meeting, 1892.

The following Fellows were in attendance upon the meeting:

F. D. Adams.
H. M. Ami.
A. E. Barlow.
Robert Bell.
H. P. H. Brumell.
Robert Chalmers.
J. S. Diller.
R. W. Ells.
B. K. Emerson.
H. L. Fairchild.
E. R. Faribault.
G. K. Gilbert.
N. J. Giroux.
U. S. Grant.
C. W. Hayes.
C. H. Hitchcock.
L. M. Lambe.
A. P. Low.
W J McGee.
W. McInnes.
R. D. Salisbury.
A. R. C. Selwyn.
T. W. Stanton.
J. B. Tyrrell.
Warren Upham.
C. R. Van Hise.
I. C. White.
G. F. Wright.

J. F. Whiteaves, Fellow-elect.

Total attendance, 29.

LIST OF

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

OFFICERS FOR 1893.

President.

SIR J. WILLIAM DAWSON, Montreal, Canada.

Vice-Presidents.

T. C. CHAMBERLIN, Madison, Wis.
J. J. STEVENSON, New York City.

Secretary.

H. L. FAIRCHILD, Rochester, New York.

Treasurer.

I. C. WHITE, Morgantown, W. Va.

Councillors.

Class of 1895.

E. A. SMITH, University, Alabama.
C. D. WALCOTT, Washington, D. C.

Class of 1894.

HENRY S. WILLIAMS, Ithaca, New York.
N. H. WINCHELL, Ann Arbor, Mich.

Class of 1893.

GEORGE M. DAWSON, Ottawa, Canada.
JOHN C. BRANNER, Little Rock, Arkansas.

Editor.

J. STANLEY-BROWN, Washington, D. C.

FELLOWS, JULY 31, 1893.

* Indicates Original Fellow (see article III of Constitution).
† Indicates decedent.

FRANK DAWSON ADAMS, Montreal, Canada; Lecturer on Geology at McGill College. December, 1889.

VICTOR C. ALDERSON, 6721 Honore St., Englewood, Ill. December, 1889.

TRUMAN H. ALDRICH, M. E., 92 Southern Ave., Cincinnati, Ohio. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

* † CHARLES A. ASHBURNER, M. S., C. E. (Died December 24, 1889.)

ALFRED E. BARLOW, B. A., M. A., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

* GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

WILLIAM P. BLAKE, New Haven, Conn.; Mining Engineer. August, 1891.

STEPHEN BOWERS, A. M., Ph. D., Mineralogical and Geological Survey of California, Ventura, California. May, 1889.

AMOS BOWMAN, Anacortes, Skagit Co., Wash. State. May, 1889.

EZRA BRAINERD, LL. D., Middlebury, Vt.; President of Middlebury College. December, 1889.

* JOHN C. BRANNER, Ph. D., Menlo Park, Cal.; Professor of Geology in Leland Stanford Jr. University; State Geologist of Arkansas.

* GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

* WALTER A. BROWNELL, Ph. D., 905 University Ave., Syracuse, N. Y.

HENRY P. H. BRUMELL, Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

* SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines. May, 1889.

ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

* T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

HENRY M. CHANCE, M. D., Philadelphia, Pa.; Geologist and Mining Engineer. August, 1890.

* † J. H. CHAPIN, Ph. D., Meriden, Conn. (Died March 14, 1892.)

CLARENCE RAYMOND CLAGHORN, B. S., M. E., 204 Walnut Place, Philadelphia, Pa. August, 1891.

* WILLIAM B. CLARK, Ph. D., Baltimore, Md.; Instructor in Geology in Johns Hopkins University.

* EDWARD W. CLAYPOLE, D. Sc., Akron, O.; Professor of Geology in Buchtel College.

AARON H. COLE, A. M., Englewood, Ill. December, 1889.

* JOHN COLLETT, A. M., Ph. D., Indianapolis, Ind.; lately State Geologist.

* THEODORE B. COMSTOCK, Tucson, Ariz.; President of the University of Arizona.

† GEORGE H. COOK, Ph. D., LL. D. (Died September 22, 1889.)

* EDWARD D. COPE, Ph. D., 2102 Pine St., Philadelphia, Pa.; Professor of Geology in the University of Pennsylvania.

* FRANCIS W. CRAGIN, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

* ALBERT R. CRANDALL, A. M., Lexington, Ky.; Professor of Geology in Agricultural and Mechanical College of Kentucky.

* WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

CHARLES WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* MALCOLM H. CRUMP, Bowling Green, Ky.; Professor of Natural Science in Ogden College.

GARRY E. CULVER, A. M., Beloit, Wis. December, 1891.

* HENRY P. CUSHING, M. S., Cleveland, Ohio; Instructor in Geology, Adelbert College.

T. NELSON DALE, Williamstown, Mass.; Assistant Geologist, U. S. Geological Survey. December, 1890.

* JAMES D. DANA, LL. D., New Haven, Conn.; Professor of Geology in Yale University.

* NELSON H. DARTON, United States Geological Survey, Washington, D. C.

* WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Assistant Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. WILLIAM DAWSON, LL. D., McGill College, Montreal, Canada; Principal of McGill University. May, 1889.

DAVID T. DAY, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

ANTONIO DEL CASTILLO, School of Engineers, City of Mexico; Director of National School of Engineers; Director Geological Commission, Republic of Mexico. August, 1892.

FREDERICK P. DEWEY, Ph. B., 621 F St. N. W., Washington, D. C. May, 1889.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

* Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

* Edwin T. Dumble, Austin, Texas; State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

* William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

* George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Eugene Rudolph Faribault, C. E., Geological Survey Office, Ottawa, Canada. August, 1891.

P. J. Farnsworth, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.

Moritz Fischer, 721 Cambridge St., Cambridge, Mass. May, 1889.

* Albert E. Foote, M. D., 4116 Elm Ave., Philadelphia, Pa.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* P. Max Foshay, M. S., M. D., 282 Prospect St., Cleveland, Ohio.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* Homer T. Fuller, Ph. D., Worcester, Mass.; Professor of Geology in Worcester Polytechnic Institute.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.

Adams C. Gill, A. B., Northampton, Mass. December, 1888.

N. J. Giroux, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Ulysses Sherman Grant, Ph. D., University of Minnesota, Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

* George B. Grinnell, Ph. D., 318 Broadway, New York city.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

* William F. E. Gurley, Sptingfield, Ill.; State Geologist.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

*James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

Henry G. Hanks, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

John B. Hastings, M. E., Boisé City, Idaho. May, 1889.

*Erasmus Haworth, Ph. D., Oskaloosa, Iowa; Professor of Natural Sciences in Penn College.

*Robert Hay, Box 562, Junction City, Kansas; Geologist, U. S. Department of Agriculture.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

Clarence L. Herrick, M. S., 324 Hamilton Ave., North Side, Cincinnati, Ohio; Professor of Geology and Biology in the University of Cincinnati. May, 1889.

*Lewis E. Hicks, Lincoln, Nebraska.

*Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, 208 S. Centre St., Pottsville, Pa.; Geologist in Charge of Anthracite District, Second Geological Survey of Pennsylvania. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

*Charles H. Hitchcock, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

*Joseph A. Holmes, Chapel Hill, North Carolina; State Geologist and Professor of Geology in University of North Carolina.

Mary E. Holmes, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.

† David Honeyman, D. C. L. (Died October 17, 1889.)

*Jedediah Hotchkiss, 346 E. Beverly St., Staunton, Virginia.

*Edmund O. Hovey, Ph. D., Jefferson City, Mo.

*Horace C. Hovey, D. D., Bridgeport, Conn.

*Edwin E. Howell, A. M., 537 15th St. N. W., Washington, D. C.

† Thomas Sterry Hunt, D. Sc., LL. D., Park Avenue Hotel, New York city. December, 1889. (Died February, 1892.)

*Alpheus Hyatt, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., Berkeley, Cal.; Professor of Mineralogy, Petrography and Economic Geology in University of California. December, 1888.

Thomas M. Jackson, C. E., Morgantown, W. Va.; Professor of Civil and Mining Engineering in West Virginia University. May, 1889.

*Joseph F. James, M. S., Department of Agriculture, Washington, D. C.

Walter Proctor Jenney, E. M., Ph. D., United States Geological Survey, Washington, D. C. August, 1891.

*Lawrence C. Johnson, United States Geological Survey, Meridian, Miss.

* WILLARD D. JOHNSON, United States Geological Survey, Berkeley, Cal.

ALEXIS A. JULIEN, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

EDMUND JÜSSEN, Ph. D., Temple, Carroll Co., Ga. December, 1890.

ARTHUR KEITH, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* JAMES F. KEMP, A. B., E. M., Columbia College, New York city; Adjunct Professor of Geology.

CHARLES ROLLIN KEYES, A. M., Ph. D., Assistant State Geologist, Des Moines, Iowa. August, 1890.

JAMES P. KIMBALL, Ph. D., Washington, D. C. August, 1891.

CLARENCE KING, 18 Wall St., New York city; lately Director of the U. S. Geological Survey. May, 1889.

FRANK H. KNOWLTON, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

* GEORGE F. KUNZ, 402 Garden St., Hoboken, N. J.

RALPH D. LACOE, Pittston, Pa. December, 1889.

GEORGE EDGAR LADD, A. B., A. M., 81 Oxford St., Cambridge, Mass. August, 1891.

J. C. K. LAFLAMME, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

LAWRENCE M. LAMBE, Ottawa, Canada; Artist and Assistant in Paleontology and Geological Survey of Canada. August, 1890.

ALFRED C. LANE, Ph. D., Houghton, Mich.; Assistant on Geological Survey of Michigan. December, 1889.

DANIEL W. LANGDON, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

ANDREW C. LAWSON, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

* JOSEPH LE CONTE, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

* J. PETER LESLEY, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

FRANK LEVERETT, B. S., 4103 Grand Boulevard, Chicago, Ill.; Assistant U. S. Geological Survey. August, 1890.

JOSUA LINDAHL, Ph. D., Springfield, Ill.; State Geologist. August, 1890.

WALDEMAR LINDGREN, U. S. Geological Survey, Washington, D. C. August, 1890.

ROBERT H. LOUGHRIDGE, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

ALBERT P. LOW, B. S., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

THOMAS H. MCBRIDE, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

HENRY MCCALLEY, A. M., C. E., University, Tuscaloosa County, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

RICHARD G. MCCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

JAMES RIEMAN MACFARLANE, A. B., Pittsburg, Pa. August, 1891.

* W J. MCGEE, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., Bloomington, Ind.; Associate Professor of Geology in Indiana State University. August, 1892.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

* Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

* Albro D. Morrill, A. M., M. S., Clinton, N. Y.; Professor of Geology in Hamilton College.

Thomas F. Moses, M. D., Urbana, Ohio; President of Urbana University. May, 1889.

* Frank L. Nason, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

* Henry B. Nason, Ph. D., M. D., LL. D., Troy, N. Y.; Professor of Chemistry and Natural Science in Rensselaer Polytechnic Institute.

* Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio.

*† John S. Newberry, M. D., LL. D. (Died December 7, 1892.)

Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

* Edward Orton, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

* Amos O. Osborn, Waterville, Oneida Co., N. Y.

*† Richard Owen, LL. D. (Died March 24, 1890.)

* Horace B. Patton, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

* William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

* Franklin Platt, 1319 Walnut St., Philadelphia, Pa.

* Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

William B. Potter, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

* John W. Powell, Director of U. S. Geological Survey, Washington, D. C.

* John R. Procter, Frankfort, Ky.; State Geologist.

* Charles S. Prosser, M. S., Topeka, Kan.; Professor of Geology in Washington College.

* Raphael Pumpelly, U. S. Geological Survey, Newport, R. I.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, A. M., Ph. D., LL. D., Middleton, Conn.; Professor of Geology in Wesleyan University. August, 1890.

* Eugene N. S. Ringueberg, M. D., Lockport, N. Y.

Charles W. Rolfe, M. S., Urbana, Champaign Co., Ill.; Professor of Geology in University of Illinois. May, 1889.

* Israel C. Russell, M. S., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

* James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Topeka, Kan. May, 1889.

* Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.

* Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

William B. Scott, M. A., Ph. D., Princeton, N. J.; Professor, College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada. December, 1889.

* Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

* John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

* J. W. Spencer, A. M., Ph. D., Atlanta, Georgia; State Geologist.

Joseph Stanley-Brown, Assistant Geologist U. S. Geological Survey, Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. Geological Survey, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. August, 1891.

* John J. Stevenson, Ph. D., LL. D., University of the City of New York; Professor of Geology in the University of the City of New York.

George C. Swallow, M. D., LL. D., Helena, Montana; State Geologist; lately State Geologist of Missouri, and also of Kansas. December, 1889.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

Maurice Thompson, Crawfordsville, Ind.; lately State Geologist. May, 1889.

* Asa Scott Tiffany, 901 West Fifth St., Davenport, Iowa.

* James E. Todd, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* Henry W. Turner, U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

* Edward O. Ulrich, A. M., Newport, Ky.; Paleontologist of the Geological Survey of Minnesota.

* Warren Upham, A. B., Assistant Geological Survey of Minnesota; Minneapolis, Minn.

* Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

* Anthony W. Vogdes, Alcatraz Island, San Francisco, Cal.; Captain Fifth Artillery, U. S. Army.

Charles Wachsmuth, M. D., Burlington, Iowa. May, 1889.

* Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

* Charles D. Walcott, U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Lester F. Ward, A. M., U. S. Geological Survey, Washington, D. C.; Paleontologist U. S. Geological Survey. May, 1889.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey, Washington, D. C. May, 1889.

* Israel C. White, Ph. D., Morgantown, W. Va.; Professor of Geology in West Virginia University.

* Charles A. White, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Joseph Frederic Whiteaves, Ottawa, Canada; Paleontologist and Assistant Director Geological Survey of Canada. December, 1892.

* Robert P. Whitfield, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

Charles L. Whittle, West Medford, Mass.; Assistant Geologist U. S. Geological Survey. August, 1892.

* Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* George H. Williams, Ph. D., Johns Hopkins University, Baltimore, Md.; Professor of Inorganic Geology in Johns Hopkins University.

* Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

* † J. Francis Williams, Ph. D., Salem, N. Y. (Died November 9, 1891.)

* Samuel G. Williams, Ph. D., Ithaca, N. Y.; Professor in Cornell University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

* † Alexander Winchell, LL. D. (Died February 19, 1891.)

* Horace Vaughn Winchell, 1306 S. E. 7th St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

* Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

* Arthur Winslow, B. S., Jefferson City, Mo.; State Geologist.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Instructor in Petrography, Harvard University. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

Lorenzo G. Yates, M. D., Santa Barbara, Cal. December, 1889.

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